PHD

The management of innovative projects by university scientists: an exploratory study of PM practices and performance in biotechnology sector

Chang, Teh-Yuan

Award date:
2006

Awarding institution:
University of Bath

The Management of Innovative Projects by University Scientists: An Exploratory Study of PM Practices and Performance in Biotechnology Sector

Teh-Yuan Chang

A thesis submitted for the degree of Doctor of Philosophy
University of Bath
School of Management
September 2006

Abstract

This study explored the management of university-industry collaborations (UICs). Although increasingly important for delivering innovation in many sectors, policy research has expressed concern about the detailed performance of these inter-organisational arrangements. Moreover, although well researched as a knowledge-based economic phenomenon there is much less equivalent managerial research, especially from the perspective of university scientists. Therefore, owing to the paucity of such research, this thesis investigated the adoption of particular project management (PM) practices by university scientists and their subsequent impact on innovative project performance. Four research questions were defined and they were developed, refined and tested within a two-stage process.

The findings from the exploratory phase indicated that three specific PM practices: Defined Project Objective (DPO), Defined Project Milestones (DPM) and Regular Progress Monitoring (RPM) best characterised the managerial ‘toolbox’ deployed by university scientists working on UICs. Additionally, four key performance measures: Meeting Objective within Proposed Schedule (MOPS), Achieving Objective (AO), Continuously Receiving Research Funding (CRRF) and Numbers of Scientific Citation Index papers published (SCI) were highlighted. The preliminary interviews suggested that the PM practices positively contribute, albeit differentially, to innovative projects’ performance as calibrated by the four measures. The work also highlighted a degree of contingency, with project purpose and structure influencing the adoption ‘level’ of the different PM practices. Based on these preliminary findings, the research questions were refined and a survey was conducted in the explanatory phase. During 2005, questionnaire data was collected from 157 university scientists who were the Principle Investigators of the innovative projects granted by the Taiwanese National Research Council and working in biotechnology and its relevant departments at around twenty universities in Taiwan. As there was only a small group of them, who were working on developmental projects, they were excluded from statistical analyses. That is, 147 respondents working on either basic or applied projects, were included in the quantitative treatments. The main statistical tests deployed were regressions and independent sample *t* tests, in order to address the refined research questions, which emerged after the qualitative investigation. The findings from this revealed that the university scientists used these three PM practices to manage innovative projects, and, specifically, they *regularly* and *irregularly* deployed RPM, which they typically engaged in defining/redefining project milestones rather than objectives, during the project life cycle. The *regular* RPM refers to the scheduled meetings for progress monitoring, whereas the *irregular* RPM indicates the unscheduled communications, mostly about the results of experiments and the exchanging of the ideas for further progress. The findings indicated that the greatest positive contribution to project performance was made by the usage of DPM and RPM together. Furthermore, the adoption of the PM practices had the greatest impact on MOPS (i.e. efficiency), less impact on AO and CRRF and no significant impact on SCI. Moreover, although CRRF was, unsurprisingly, significantly correlated with SCI, the analysis suggested that MOPS rather than AO significantly correlated with CRRF. Whilst the project purpose and structure insignificantly influenced the level of use of DPO, the former significantly influenced the level of use of DPM and RPM, and the latter affected that of RPM.

The study concluded that university scientists often define/redefine project milestones through *regular* and *irregular* research meetings, during the project life cycle. This process enhances the efficiency of the projects, because the use of DPM and RPM together positively contributes to MOPS. Owing to the significant correlation between MOPS and CRRF, the projects are more likely to receive follow-up funding when such enhancement is applied. This could positively contribute to the numbers of SCI papers published, because there is a significant correlation between CRRF and SCI. Accordingly, in practice, the work suggests that university scientists should pay more attention to the use of PM practices for securing their research funding and increasing the numbers of publications of SCI papers.

Acknowledgement

This study was partly founded by the Ministry of Education, Taiwan (MOE) through their Studentship Programme. I gratefully acknowledged the MOE for their financial assistance.

The composition of this thesis owes much to the knowledge and expertise of others in both the academic and industrial areas in the management and biotechnology sectors. I would like to thank all those at the biotechnological sector in Taiwan who participated in the study, particularly to those who participated in the interviews. Their valuable information and time made this study possible.

I would like to thank my supervisors Professor Michael Lewis and Dr Harvey Maylor for their constructive supervision throughout the period of the study, contributed significantly to the development and completion of this study. I would like to thank Professor Erling Andersen (also served as the external examiner on the thesis) at the BI Norwegian School of Management, Norway, Doctors Thomas Johnsen (who also been the internal examiner) and Alistair Brandon-Jones at the School of Management, University of Bath, UK and Kate Blackmon, at Saïd Business School, University of Oxford, UK for their critical but invaluable comments on my work, and to the completion of this thesis.

This work would not have been possible without the ongoing assistance and support of my family. My wife, Yun-Ju, and daughter, Yun-Chia, inspire me to complete the study. My parents, parents-in law, brother and sister have always provided their assistances in many areas and shared my responsibility to the members of my family. I dedicate this work to all of members of my family. Finally, I will be grateful to my colleagues who have given any assistance to me during the period of the study. Thank you very much.

Table of Contents

Table of Contents

Lists of Tables:

Lists of Figures:

Chapter One: Introduction

Despite the growing importance of university-industry collaborations (UICs), especially in the biotechnology sector (e.g. Oliver, 2004; Pisano, 2006; Powell & Owen-Smith, 1997), it has been suggested that these arrangements could often underperform; particularly with respect to cost and schedule (e.g. Kelly, Schaan, & Joncas, 2002; Shohet, 2004). Motivating this thesis are parallel observations concerning the UIC phenomenon. First, despite these performance concerns collaborative projects in general, and UIC projects in particular, are increasingly seen as key components of 'fifth generation' innovation models (Rothwell, 1994) in a range of sectors (Hagedoorn, 2002). Second, the management of UIC projects remains relatively under-researched, in particular, the often dominant role (Pisano, 2006) played by university scientists. In general terms, the purpose of this study is to build a more comprehensive understanding of how university scientists manage innovative projects and, specifically, how various project management (PM) practices are selected and implemented by them, when working on a range of different innovative biotechnology projects.

1.1. University-Industry Collaboration

In the past two decades, increasing numbers of UICs have been arranged, owing to the changes in innovation processes (Rothwell, 1994), and the altering of the knowledge production process (Gibbson, Limoges, Nowotny, Schwartzman, Scott, & Trow, 1994). Regarding the former, since the fourth generation of innovation process, most of the innovations established in industries sought to link suppliers and customers, and struggled against time pressures (Miller & Morris, 1998). Subsequently, the fifth generation process focused on coordinating integrated networks from different parties, to gain the ability of being rapid in product development (Iansiti & West, 1997; Rothwell, 1994), e.g. seeking opportunities to collaborate with universities to access new knowledge and technologies for developing new products or services faster. Thus, universities have become more integrated into national innovation systems than ever before, and the consequential growth of regional and national economies has been acknowledged (Cohen, Florida, Randazzese, & Walsh, 1998; Cohen & Levinthal, 1990; Dasgupta & David, 1994; Etzkowitz, 1998; Lee, 2000; Mansfield & Lee, 1996; Pavitt, 1991, 2001). Contributions by the UICs to the economy include: increasing the performance of the collaborating firms in terms of the productivity of innovation processes (David, Mowery, & Steimmueller, 1992; Zucker & Darby, 2000), the absorptive capability (Cohen & Levinthal, 1990) and the improvement of the economic relevance of scientific knowledge production (Gibbson, 1997).

With respect to the change in the knowledge production process, this has shifted from Mode 1 to Mode 2, i.e. from a linear process to a cyclical process. Mode 1 is mono-disciplined and makes a distinction between fundamental and applied research. That is to say, the process employed in Mode 1 generates knowledge “within a disciplinary, primarily cognitive, context” (Gibbson et al., 1994, p. 1). In comparison, Mode 2 is multi-disciplined and proceeds in a constant flow back and forth between fundamental and applied research, that is, between the theoretical development and the practical use. Thus, Mode 2 produces knowledge “in a border, trans-disciplinary social and economic context” (Gibbson et al., 1994, p. 1). Consequently, one of functions of universities, i.e. the creation of knowledge, has been transformed to the creation, distribution and application of knowledge (Etzkowitz, Webster, Gebhardt, & Terra, 2000). This change has led to the increasing amounts of UICs.

Moreover, UICs have been recognised as one of the most important drivers of innovation, allowing for the delivery of scientific outcomes across the boundary between pre-discovery and post-discovery stages, as will be shown later (see Figure 1.1 below) (Cohen & Levinthal, 1990; Feller, Ailes, & Roessner, 2002; Khilji, Mroczkowski, & Bernstein, 2006; Mansfield, 1998). This is particularly true in the fields where the degree of maturity of scientific knowledge is low, e.g. the biotechnology industry. That is to say, knowledge production organisations, e.g. universities, may provide novel scientific knowledge and cutting-edge technologies to industries through UICs, and then industrial firms develop and launch new products or services to the markets. For instance, Figure 1.1 (adapted from Khilji et al., 2006, p. 530) below shows a typical innovation process in the biotechnology industry. This model indicates five different stages: basic research, innovation and invention, early-stage technology development, product development, and production and marketing. Moreover, basic research, innovation and invention are placed in the pre-discovery stage; the others are seen as being in the post-discovery stage. In addition, the range of sources of research funding in the biotechnology sector, including the funding to university scientists and industrial firms, can be seen to be substantial during the pre-discovery stages and post-discovery stages (Khilji et al., 2006; Oliver, 2004; Pisano, 2006; Zucker & Darby, 1998). For instance, in

Taiwan, the SBIR (Small Business Innovation Research) programme has been established by the Ministry of Economic Affairs (MOEA), and aims to enhance the innovative capability of small and medium-sized enterprises (SME) through UICs (NSC, 2003).

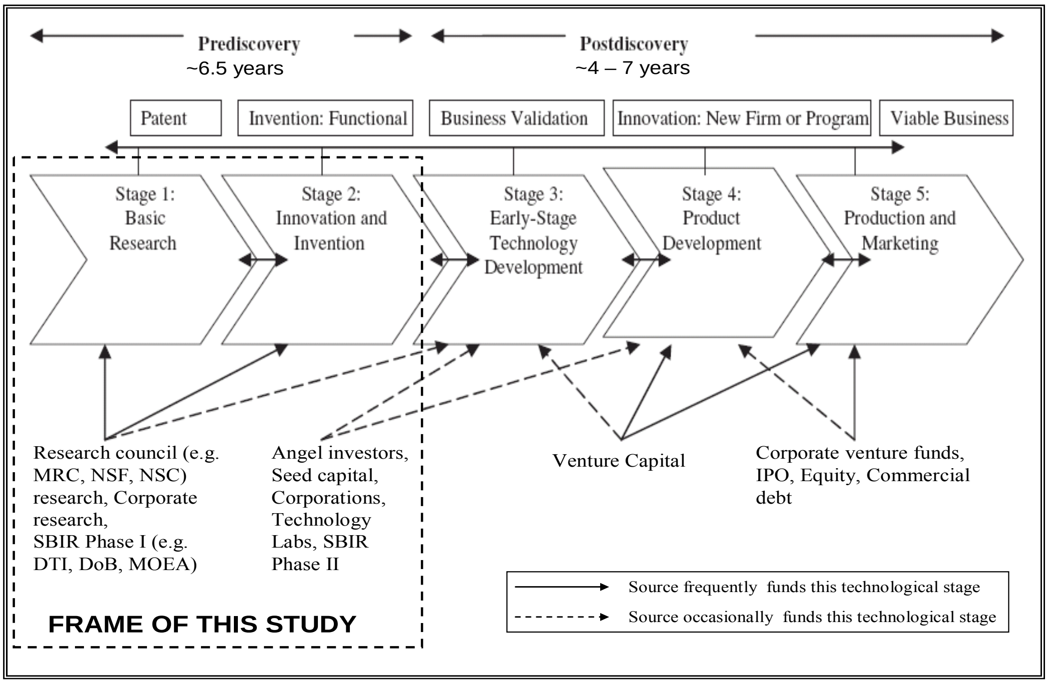

Figure 1.1: A Typical Innovation Process in the Biotechnology Industry and the Boundary of This Study

(Source: Adapted from Khilji, S. E., Mroczkowski, T., & Bernstein, B. 2006. From invention to innovation: toward developing an integrated innovation model for biotechnology firms. Journal of Product Innovation Management, 23(6): 528-540.)

Most of the university scientists in the biotechnology sector involve themselves in the UICs established at the pre-discovery stage, and they are most likely to be the key players (Oliver, 2004; Pisano, 2006). That is to say, in the biotechnology sector, university scientists are mostly involved in the established UICs at the pre-discovery stage, and during this period are mainly in charge of their implementation, as compared with the other stakeholders, e.g. funding bodies, industrial collaborators (e.g. McMillan, Narin, & Deeds, 2000; Pisano, 2006; Tapon, Thong, & Bartell, 2001).

There are several processes adopted to organise UICs (e.g. joint venture, joint research), and they are usually organised as project-based activities (Jordan, Hage, Mote, & Hepler, 2005). Such projects are often seen to embody the fast moving, adaptable and flexible systems of production and service delivery that are common in a knowledge-based economic system (Mintzberg & McHugh, 1985), and firms being involved with universities allows them to access new knowledge and technologies more effectively and efficiently (Liebeskind, Oliver, Zucker, & Brewer, 1996). Following this view, UICs can be seen as research and development (R&D) projects for new scientific knowledge and technologies (hereafter, innovative projects), and university scientists usually have the role of the Principle Investigators (PIs) in established UICs at the pre-stage of the innovation cycle. This is particularly true in highly innovative environments, such as the biotechnology industry (e.g. Oliver, 2004; Pisano, 2006). With respect to this, the terms, 'R&D project' and 'innovative project', are interchangeable in this study.

1.2. Problem Statement

Given the importance of UICs in the innovation process, industrial managers and top management are always concerned about their contributions to firms' technological competitiveness. Nevertheless, since the 1990's dramatic change in the competitive context (e.g. technology fusion, shortened innovation cycle, intensified competition) have fostered the development and adoption of a new array of managerial approaches for ensuring the efficiency and effectiveness of UICs (Ortt & Smits, 2006). However, today firms still struggle to find efficient and effective processes and management activities for them. In fact, Kelly *et al.* (2002) pointed out that a number of studies have suggested that the failure rate of UICs established in the high-tech sectors was in the 50-60% range (Dacin, Hitt, & Levitas, 1997; Duysters, Kok, & Vaandrager, 1999; Kok & Wildeman, 1998; Spekman, Lynn, MacAvoy, & Forbes III, 1996). UICs established in the biotechnology sector have been seen as the most successful examples (e.g. Oliver, 2004; Pisano, 2006), yet most biotechnology firms are confronted with low efficiency and effectiveness (Amir-Aslani & Negassi, 2006; Edwards, Murray, & Yu, 2003; Schmid & Smith, 2002; Shohet, 2004). For instance, Giesecke (2000) and Kaiser and Prange (2006) reported that UICs between the German pharmaceuticals industry and universities, usually run behind budget and schedule. A similar phenomenon has been observed in Canada (Tapon et al., 2001) and Taiwan (Chang, 2003; Sun, 2004a, 2004b).

Whilst biotechnology firms encounter low efficiency and effectiveness for UICs, they continue to rely heavily on collaboration with university laboratories, particularly for basic research in order to strengthen their competitive advantage (Pisano, 2006; Tapon et al., 2001). UICs need a greater amount of management effort and capability for coping with the problem regarding low efficiency and effectiveness, because the key to successful collaboration lies the way in which they are managed and the quality of that management (Dodgson, 1993). Moreover, Pangarkar (2003) concluded that, in broad terms, 83% of the factors obstructing the success of UICs are associated with management issues. As a result, there is a need to provide a better understanding for the management of UICs. Thus, for this study the aim is set out as:

- Aim of study: providing more relevant knowledge for better management of UICs.

For the reasons that follow, the research problem for this work in order to achieve this aim is:

- Research Problem: how do university scientists manage innovative projects, and how does this management impact on the performance of such projects?

Firstly, it has been argued that project leaders, i.e. PIs, can help the management to maximise the performance of innovative projects (Afuah, 1998; Cordero, Farris, & DiTomaso, 2004; Katz, 1997). In addition, as mentioned, university scientists mostly play the role of PIs for the innovative projects in the frame of this work. Secondly, innovative projects that university scientists are involved in would need different managerial approaches, as their educational and cultural backgrounds are different to those who are working in industrial firms (Amabile, 1996, 2001; Sapienza, 2005). Thirdly, as stated, this work is focused on the innovative projects established at the pre-discovery stage of the innovation cycle and are usually seen as radical innovative projects (Roussel, Saad, & Erickson, 1991). In addition, it is suggested that the managerial approaches employed in such projects would be different to those used in incremental and moderate ones, as those used in the latter may actually be counterproductive in the context of a highly innovative, discontinuous environment (Leifer, McDermott, O'Connor, Peters, Rice, & Veryzer, 2000; Salomo, Gemünden, & Leifer, 2007; Veryzer, 1998). Finally, the exploration of the management of innovative projects, from the university scientists' viewpoint, should not be restricted only to UICs. Attention should also be paid to how they manage academic innovative projects, which are mainly basic and applied research, and are mostly structured as individual works, i.e. not working with outside bodies (Chiesa, 2001). That is because they usually undertake such projects at the same time as when they are involved in UICs, and their mentality when carrying out individual (academic) projects could also be being employed in a concurrent UIC (BHEF, 2001; Cohen, Duberley, & McAuley, 1999b; Miller, 1986; Terziovski & Morgan, 2006). Therefore, there is a need to understand how university scientists manage innovative projects, in order to provide relevant knowledge to the stakeholders who have interests in UICs. However, research in this area is very limited and this provides the motivation for this study to explore how university scientists manage innovative projects, and how this management impacts on the performance.

1.3. Context

This study explores how university scientists manage innovative projects in the biotechnology sector. This sector has been chosen because, firstly, the author worked in the sector for over ten years. Secondly, the biotechnology sector is one of the most innovative and scientifically intensive fields because of its level of maturity of scientific knowledge being low (Cardinal, Alessandri, & Turner, 2001; Gay & Dousset, 2005; Meyer-Krahmer & Schmoch, 1998; OECD, 2006; Pisano, 1994). Finally, biotechnology firms are more likely to have close ties to universities in order to access and exploit scientific knowledge and technologies, and enhance their competitive advantage (e.g. Audretsch & Stephan, 1996; Hall & Bagchi-Sen, 2007; Mansfield, 1998; McMillan et al., 2000; Meyer-Krahmer & Schmoch, 1998; Pisano, 2006; Tapon et al., 2001).

In the context of innovative projects, university scientists could be involved in them for different purposes (Chiesa, 2001), i.e. basic, applied and developmental research (OECD, 1980), and they may have different structures, i.e. individual and collaborative projects running concurrently (Cohen, Duberley, & McAuley, 1999a; Turpin & Deville, 1995; Turpin, Garrett-Jones, & Rankin, 1996). This may result in different degrees of uncertainty (Turner & Cochrane, 1993) and innovativeness (Roussel et al., 1991), and it is likely to lead to varying approaches in managing the innovative projects, including the ways of measuring their performance (Chiesa & Frattini, 2007; Salomo et al., 2007; Turner & Cochrane, 1993). However, literature on these observations from the university scientists' perspective is scarce, and stimulates this researcher into such an exploration, so as to counter the lack of knowledge about this subject. Therefore, there is a need to investigate how the purposes and structure of innovative projects influence the employment of management approaches by university scientists.

1.4. Research Questions

The focus of this study is UICs established in the pre-discovery stage of the innovation cycle (Figure 1.1). However, the evidence suggests that such projects still have a tendency to suffer from low efficiency and effectiveness. There is a need to understand the factors (e.g. contextual factors and management process) related to the efficiency and effectiveness of UICs. For example, some literature has focused on the identification of factors associated with the success of UICs from several perspectives: the development of UICs (e.g. Kenney, 1986; Powell, Koput, & Smith-Doerr, 1996; Zucker & Darby, 1998), the institutional governance of such collaboration (e.g. Casper, 2000; Giesecke, 2000; Gittelman, 2006; Kaiser & Prange, 2006), the interactions between organisations, and between individuals and organisations (e.g. Oliver, 2004; Rothaermel & Deeds, 2006), and dimensions of performance for UICs (e.g. Chiesa, 2000; Chiesa & Frattini, 2007; Chiesa & Masells, 1996; Pappas & Remer, 1985; Poh, Ang, & Bai, 2001). Moreover, considerable numbers of success factors have been identified (e.g. Davenport, Davies, & Grimes, 1999; van der Panne, van Beers, & Kleinknecht, 2003). Some of identified factors have been categorised into seven themes – 'choice of partner', 'environmental factors', 'cultural gap', 'project management', 'ensuring equality' and 'universal success factors' – in a best practice model for managing UICs (Barnes, Pashby, & Gibbons, 2006).

In the model, the PM theme could appear to be in central position, because the other themes are all likely to influence the choice of management approach. For example, as mentioned in the previous section, outside stakeholders involved in a UIC, and differences in cultural and educational background would affect the management style. Moreover, PM theory suggests that employing PM practices by project managers can effectively achieve the planned project outcomes (PMI, 2004). In fact, PM practices have been successfully applied to manage projects that are relatively structured and predictable, e.g. construction projects. In addition, they have also been employed in managing new product development (NPD) projects (e.g. Bonner, Ruekert, & Walker Jr, 2002; Keegan & Turner, 2002; Omta & de Leeuw, 1997;

Salomo et al., 2007), whose degree of uncertainty, in general, is seen as high (Turner & Cochrane, 1993). Finally, regarding the function of PM, it has the purpose of: initiating, planning, executing, monitoring and controlling, and closing activities so that the project is completed as successfully as possible, in spite of all the uncertainty (PMI, 2004). These are usually seen as essential in industrial NPD teams for keeping them on track and avoiding unwelcome surprises (Bonner et al., 2002; Burns & Stalker, 1961; Moorman & Miner, 1998). In other words, PM practices are still considered to be one of management's main tools for keeping industrial R&D projects on schedule, within budget, and aligned with the strategic goals (Cooper & Kleinschmidt, 1995). This suggests that PM practices could be employed in managing innovative projects that university scientists are involved in, in order to conduct such projects more efficiently and effectively. Although this view appears to conflict with the nature of innovative projects, i.e. high degrees of freedom, uncertainty and flexibility (Turner & Cochrane, 1993).

However, literature on how university scientists use PM practices is lacking and this study intends to address this gap, in order to contribute to providing a more comprehensive understanding of how they manage innovative projects. Hence, it is necessary to explore the extent to which university scientists employ PM practices in managing these projects. As a result of this, the first research question has been formulated as:

- RQ 1: to what extent do university scientists (Actor) use PM practices (Process) to manage innovative projects?

Moreover, this work intends to explore whether the purpose and structure of innovative projects (contextual factors) influence the level of employment of PM practices. The actors (i.e. university scientists) may adopt different management techniques depending on variations in these two factors as mentioned in section 1.3. Therefore, the second research question of this work is:

- RQ 2: how do the structure and purpose of innovative projects impact on the use of PM practices (Process) by university scientists (Actor)?

Another objective of this study is to understand the impact of the PM practices employed by university scientists on the performance of innovative projects. In order to address this question, the measurements for assessing the performance of such projects, from the university scientists' perspective, need to be investigated, as their preferences on this matter may be different to those of other stakeholders (Chiesa & Frattini, 2007; Omta & de Leeuw, 1997). Hence, the third research question is:

- RQ 3: how do university scientists (Actor) measure the performance of innovative projects (Outcome)?

Once the above research questions 1 and 3, have been addressed, this study can further investigate to what extent the employment of PM practices influences the project performance of innovative projects. Thus, the final research question is formulated as:

- RQ 4: what impacts does the use of PM practices (Process) have on the performance of innovative projects (Outcome)?

1.5. Initial Framework

Drawing from the above, an initial framework for this study has emerged, illustrated in Figure 1.2 below. This initial framework describes how this study sets out to explore to what extent university scientists employ PM practices to manage innovative projects, the effectiveness of the employment of these practices on the performance of the projects, and whether the structure and purpose of the projects influence the levels of usage of PM practices. Figure 1.2 depicts an initial framework that distinguishes between the core areas of interest. This conceptual framework addresses the research questions concerning: the influence of the purpose and structure of innovative projects, regarding the level of employment of PM practice, the use of PM practices, the performance measurements for the projects, and the impact of such usage on the level of performance.

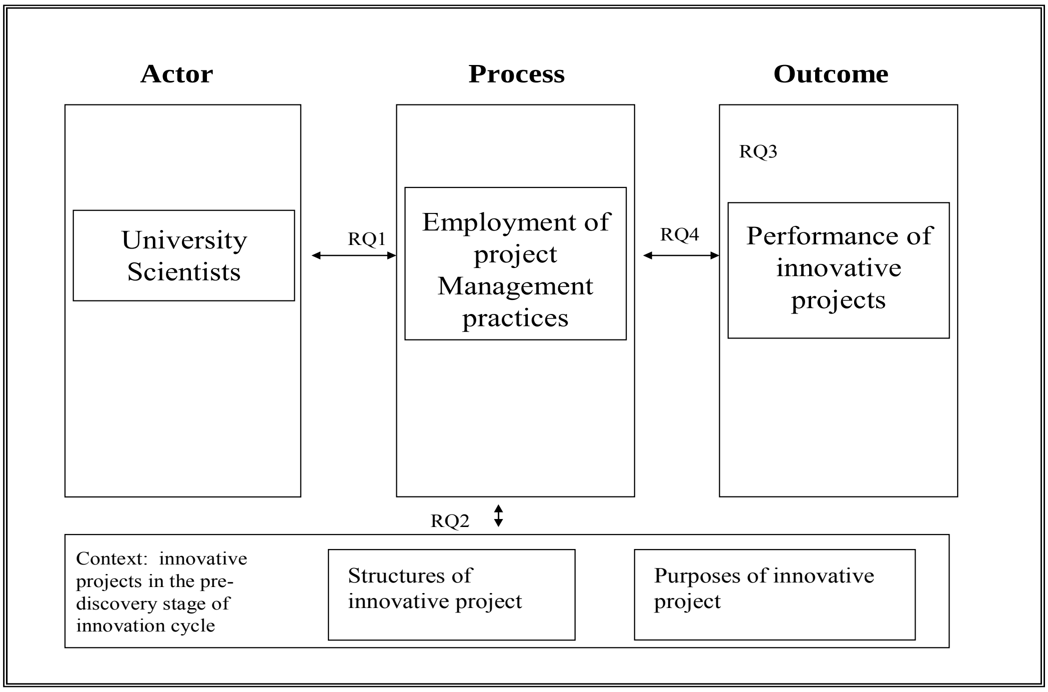

Figure 1.2: The Initial Framework of this Study

1.6. Structure of the Thesis

This thesis is organised as follows. Chapter two provides a more detailed discussion on the constructs mentioned in this chapter, in order to build up a more comprehensive framework for this study. That is to say, there is a literature review, including a critical investigation of current theory and practice, so as to develop a justification for the research questions of this study. In addition, the elements of the constructs in the conceptual framework will be introduced at the end of the literature review.

The third chapter includes the methods and techniques used to investigate the research questions. Owing to the current lack of evidence to answer the research questions formulated in this study, exploration of the major concepts is proposed, through qualitative analysis, as the starting point. Moving forward, an explanatory step, drawing on quantitative data is undertaken in order to address the research questions in more depth and to consider generalisability. In addition, the quality of findings is discussed.

Chapter four presents the findings obtained from the exploratory phase, addressing the research questions listed above. The meanings of the findings are discussed, in order to shed more light on the appropriateness of the research questions and the conceptual framework posited previously. As a result, a more specific framework is established, and a set of more detailed research questions are formulated at the end of this chapter. These are employed in the explanatory phase.

In Chapter five the explanatory results concerning the revised framework and research questions are presented, in which an overview of the significant findings of this study is given. Also, the results are discussed in light of the existing literature.

Chapter six presents the discussion addressing the research questions posed. This is mainly based on the revised research questions, and the difference in the findings between the exploratory and explanatory phases.

Chapter seven examines the limitations of this study. The conclusions are presented, in terms of contributions to knowledge, and the theoretical and practical implications of the findings. Finally, proposals for further research are put forward.

1.7. Chapter Summary

This chapter has provided the background to this thesis. The boundary of this research has been given through the perspective of: the innovation cycle, the management of innovation and the management of projects. In addition, the research questions to be addressed have been identified. These are:

- RQ 1: to what extent do university scientists (Actor) use PM practices (Process) to manage innovative projects?
- RQ 2: how do the structure and purpose of innovative projects impact on the use of PM practices (Process) by university scientists (Actor)?
- RQ 3: how do university scientists (Actor) measure the performance of innovative projects (Outcome)?
- RQ 4: what impacts does the use of PM practices (Process) have on the performance of innovative projects (Outcome)?

Chapter Two: Literature Review

The initial conceptual framework and the research questions have been formulated in Chapter One. The framework is shown again as Figure 2.1 in this chapter for guiding the process of reviewing the literature, leading to a more comprehensive framework. The purpose is to provide evidence to support the developed conceptual framework and research questions shown in Chapter One. This can help pursue the objectives of this study and support the subsequent empirical analysis.

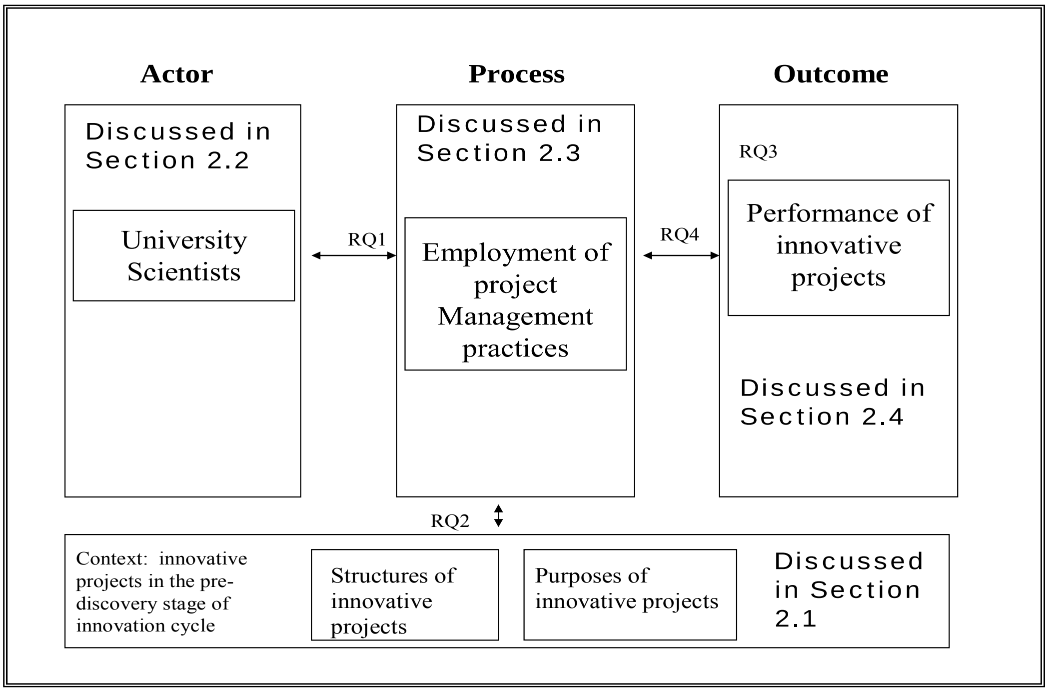

Figure 2.1: Illustration of the Structure of Chapter Two

This chapter is structured as shown in Figure 2.1. In Chapter Two, the context construct will be discussed first, because such an approach could give a better springboard for discussion about for the Actor, Process and Outcome constructs, leading to the formulation of research questions 1, 3 and 4. Thus, research question 2 will be presented before the others. Section 2.1 presents the context of this study, and the rationales of adopting the purpose and structure of innovative projects as the contextual factors. The characteristics of the context will be discussed, leading to the identification of the research question related to contextual variables. Section 2.2

describes the theories regarding the ways in which actors (university scientists) use managerial practices to manage innovative projects, and identifies the gap in the literature which is to be addressed by this study. Section 2.3 presents the current body of knowledge on the management of innovative projects from the PM perspective. The following section, 2.4, shows the dimensions of the selection of the measurements for assessing the performance of innovative projects. Section 2.5 is the chapter summary.

2.1. Context

The focus of this study is the innovative projects established in the pre-discovery stage of the innovation cycle (Figure 1.1). That is to say, the nature of the projects in this study is associated with the innovation cycle. Thus, it is necessary to review the literature related to the characteristics of innovation, in order to understand the context better and identify research question 2.

2.1.1. What is innovation?

Innovation derives from the Latin word *innovare*, which means to 'make something new'. It can be regarded as the process of transforming change into new ideas and opportunities, developing different business processes, and delivering new products or services to the original field (Drucker, 1985). This concept is consistent with the definition of innovation made by the UK DTI (Department of Trade and Industry) as: "the successful exploitation of new ideas". This definition differentiates innovation from invention: "innovation refers to a new idea or concept generated by R&D (i.e. invention), which is transformed into a socially usable product" (Khilji et al., 2006, p. 532). This echoes other researchers' views on innovation as an outcome 'a new idea, method or device' (Damanpour & Evan, 1984; Kimberly & Evanisko, 1981), as 'the process of introducing something new' (Ettlie, 1980; Rogers, 1983; Van de Ven & Rogers, 1988), or as 'a new technology or combination of technologies that offer worthwhile benefit' (Dewar & Dutton, 1986; Ettlie, 1997; Ettlie, Bridges, & O'Keefe, 1984). These views imply that the central theme of innovation is 'newness', and major innovations require new skills, levels of market understanding, leaps in new processing abilities, and systems throughout the organisation (Gopalakrishnan & Damanpour, 1997); indicating that two types of innovation exist – product innovation and process innovation. Nevertheless, innovation is categorised by other sets of ideas, such as radical vs. incremental and technical vs. administrative, as will be discussed later.

Having investigated the literature on innovation, it is difficult to find a commonly agreed definition. Gopalakrishnan and Gamanpour (1997) posited that the definitions can be categorised into three dimensions. The first perspective is concerned with the process of developing new products or services. The second perspective looks at the process of adopting new products or services. The third perspective focuses on innovation itself, analysing the extent to which new ideas, practices or objects are perceived as new by an individual, or other units of adoption, such as organisations or industries. These three perspectives are associated with the inquiry of this study. For instance, it may be important to establish the structure of the innovative projects being studied, in order to understand more deeply whether this would be a factor that influences the level of employment PM practices by university scientists in managing such projects.

2.1.2. Types of Innovation

It can be seen; from the above that innovation is a multi-faceted concept, which has generated much debate about its categorisation. There has been considerable literature on innovation; however, there is no agreed consensus regarding the placing of any one type of innovation into a particular category. Following the perspective of the development of new products/services, innovations can be categorised by the nature and degree of change, or outcomes. Martin (1984) proposed innovation can be classified into two groups – ‘normal’ and ‘revolutionary’, in terms of the degree of change to existing products/services. This suggests a fundamental transformation of the existing belief system is required to introduce a revolutionary innovation. Subsequently, research providing a more detailed distinction has followed.

In terms of the two dimensions of technology change and customer benefit, Gobeli and Brown (1987) classified innovations as ‘incremental’, ‘technical’, ‘application’ and ‘radical’. Those innovations involving a low customer benefit and low degree of technological change are defined as incremental. Those involving a low customer benefit but high degree of technological change are defined as technical innovations. Application innovations are defined as innovations high in customer benefit but having a low degree of technological change. Radical innovations are defined as those involving a high degree of both customer benefit and technological change. Similar views of these definitions have been presented by other researchers (e.g.

Crawford, 1980; Ford & Saren, 2001). This classification equally emphases the technology-driven side and customer-driven side of innovation, reflecting the technology-push and market-pull models of the innovation process (Rothwell, 1994).

Freeman (1994) ranked innovation on a five-point scale: systemic, major, minor, incremental, and unrecorded, although the most common distinction is between radical and incremental (Tidd, Bessant, & Pavitt, 2005). He defined radical innovations as those which need a new factory and/or market for their exploitation, and incremental innovation as those which require a scaling up of plant and equipment and quality improvements to products or services, for a variety of applications. The concept of innovation that has been introduced by this definition is that it is not only about change, but also about evolving something new.

Research regarding innovations with a very high degree of change has developed the concept of 'discontinuous' and 'disruptive' innovations. The former has been defined as innovations creating entirely new market offerings, with which customers may be not familiar (Abernathy & Utterback, 1988; DeTienne & Koberg, 2002). However, DeTienne and Koberg (2002) viewed discontinuous innovations more dynamically. They argued that "discontinuous innovations are not necessarily a matter of magnitude, but can comprise altered variations in technology that, over time, shift the direction of the industry … discontinuous innovation or variations in technology will augment, shift and change the firm's technological processes and products/services/programs." (p. 352). Their point of view is similar to Linton's, (2002), who argued that discontinuous innovation involved shifting from one technological learning curve to a more attractive one, thereby obtaining a substantial innovative advantage. With respect to disruptive innovation, the literature has claimed that it is associated with a higher degree of change. Disruptive innovation has usually been seen as "scientific discoveries that break through the usual product/technological capabilities and provide a basis for a new competitive paradigm" (Kassicieh, Walsh, Romig, Cumminngs, McWhorter, & Williams, 2002, p. 375).

In addition, there is also the view on the extent to which innovations are systemic, i.e. the scale. Coupling these two dimensions, innovations have been distinguished between 'minor' and 'major' innovation on the scope dimension, and 'changes to the technological system' and 'technological revolutions' on the scale dimension (Lundgren, 1995). However, the two dimensions would correlate with each other. For example, Freeman (1994) argued that 'systemic' was at the highest end of the spectrum (scope), reflecting an even higher degree of change than 'radical' (scale). This demonstrates a correlation between the changes in production and marketing system and the degree of product innovation, that is, product innovation is hard to separate from process innovation. Thus, the typology of innovations is rather complex and difficult to establish in terms of a single dimension. However, innovations have usually been categorised by researchers into sets of contrasting types. The above discussion is summarised by focusing on the three sets most often employed (Gopalakrishnan & Damanpour, 1997).

Product vs. process

Studies relating to the distinction between product and process are associated with the areas and activities that an innovation affects. Process innovations are defined as tools, devices, and knowledge in throughput technology that mediate between inputs and outputs and are new to an industry, organisation, or organisational subunits (Ettlie & Reza, 1992; Utterback & Abernathy, 1975). In contrast to process innovation, product innovations are new products or services that are introduced for the benefit of customers (Utterback & Abernathy, 1975). The rates of adoption of process and product innovations differ according to the stage of the innovation life cycle, as will be presented later (Utterback & Abernathy, 1975). In addition, firms also differ in their views on the competitive advantage of each of these two types (Ettlie, 1983).

Radical vs. incremental

Researchers identify an innovation as either radical or incremental by determining the degree of change associated with it (Ettlie *et al.*, 1984; Normann, 1971). Radical innovations produce fundamental changes in the activities of an organisation or an industry and represent clear departures from existing practices, most likely attributed to the basic research being carried out in the initial stage of the innovation process (see Figure 1.1), as will be discussed later. Radical innovations also significantly increase environmental uncertainty and result in the transformation of firms or industries (Meyer, Brooks, & Goes, 1990; Tushman & Anderson, 1986). On the other hand, incremental innovations merely call for a marginal departure from existing practices; they mainly reinforce the existing capabilities of organisations (Dewar & Dutton, 1986; Ettlie et al., 1984; Henderson & Clark, 1990).

Technical vs. administrative

The distinction between technical and administrative innovation is important because it reflects the separation between technology and social structure (Evan, 1966). Technical innovations include products, processes and technologies used to produce new products or services directly related to the basic research of an organisation (Daft, 1982; Damanpour & Evan, 1984). On the contrary, administrative innovations pertain to organisational structure; they are indirectly related to the basic research of the organisation and are more directly associated with its management (Damanpour & Evan, 1984; Kimberly & Evanisko, 1981). Technical and administrative innovations are related to the technical and administrative cores of the organisation, respectively (Daft, 1982).

2.1.3. Evolutionary Innovation Processes

This study is focused on innovative projects established in the pre-discovery stage in the innovation cycle, whose outcomes are more likely to be intangible new knowledge and technologies. Under such circumstance, the innovative projects within the boundaries of this study can be seen as technological innovation. In general, research into technological innovation focuses either explicitly or implicitly upon one of/or a combination of these stages. In reality the process of innovation is far more complex. Broadly speaking, innovation can be understood as a process consisting of several stages. For example, according to the typical innovation process in the biotechnology industry given in Figure 1.1, it can be considered as comprising three main stages: innovation generation, innovation adoption and innovation implementation. Moreover, each main stage is comprised of several sub-stages, e.g. the innovation generation stage includes idea generation, project definition, problem-solving, design, development and marketing. Whilst some theorists (e.g. Robertson, 1974; Zaltman, Duncan, & Rogers, 1973) have taken the view that these stages are of a linear fashion, others (e.g. Kline, 1985; Rogers, 1983; Rothwell, 1994) have seen these stages as a complex process with multiple and cumulative progressions of convergent, parallel and divergent activities.

Rothwell (1992) noted the diversity of approaches evident in the management of innovative projects, such as NPD projects, and attempted to define these in terms of their historical occurrence. This has resulted in a typology of processes, based on five historical generations (Rothwell, 1994). The evolution of the management of innovative projects is summarised in Table 2.1. It is one of many categorisations of the development of innovation processes. Cooper (1994), for instance, also used an historical analysis, identifying three generations of process. There are significant deficiencies in these classifications of innovation processes, which need to be addressed – the generational model being too broad and only representative of an intention, rather than possessing measurable characteristics (Maylor, 2001). Considerable discrepancy in the firms within this broad group is evident in practice, although again, not considered within the literature.

Table 2.1: Summary of Five Generations of Innovation Process from an Evolutionary Perspective

Generations	Context	Innovation process descriptions	Characteristics
First generation	Rapid economic growth, demand exceeding production capacity. Innovation was seen as ‘black hole demand’. (1950s – mid 1960s)	Technology-push model. Industry innovation was generally perceived as a linear and sequential progression from scientific discoveries, through development in firms, to the marketplace.	Innovation focuses on scientific breakthrough, i.e. R&D, seen as in ivory tower. It is seen as an overhead cost, having little or no interaction with the rest of the company or overall strategy. The market will take whatever companies produce.
Second generation	Steady economic growth, the relationship between demand and supply towards balance. Innovation was seen as ‘market share battle’. (mid 1960s – early 1970s)	Market-pull model. Industry innovation process remained a linear and sequential progression. However, the perceptions of the process have begun to change with a shift towards emphasising demand side factors, i.e. marketplace.	Innovation focuses on market (i.e. business), mostly driven by firms’ business strategies. Most of innovations are under the umbrella of project management and the internal customer concept.
Third generation	High rates of inflation and demand saturation, associated with concerns with accountancy and financing issues. Innovation was viewed as rationalisation effort. (early 1970s – mid 1980s)	Coupling model. It was still essentially by a sequential process, but in these cases with feedback loops, i.e. a more general process of interactions between, on the one hand, technological capabilities and, on the other hand, market needs.	Innovation is seen as portfolio activities, moving away from individual projects view. There is a linkage to both business and corporate strategies, i.e. innovation and marketing are more in balance. Risk-reward and similar methods guide the overall investments.
Fourth generation	Economic recovery, growing awareness of the strategic importance of evolving generic technology, increased strategic emphasis on technological accumulation (technology strategy), shortening product life cycle (time-based strategy). Innovation was seen as time-based struggle (early 1980s – early 1990s).	Rugby or integration model. Innovation process horizontal collaborates with external suppliers and different internal departments into the new product development process. These involvements were working the project simultaneously (in parallel).	Innovation emphasises linkages with both suppliers and customers. It is seen as an integrated activity, learning from customers and moving away from a product focus to a total concept focus in which activities are conducted in parallel by cross-functional teams.
Fifth generation	Fast innovation was seen increasingly as an important factor determining a company’s compositeness, rates of technological change were high, product life cycle was short, strongly emphasising product quality and features. Innovation was seen as system integration. (early 1990s onward)	Integration and networking model. The industry innovation process with greater overall organisational and system integrations and networking.	Innovation is seen as a network, focusing on collaborating with competitors, suppliers, distributors, etc. the ability to control product development speed is imperative.

Sources: adopted and developed from Chesbrough, H. W. 2003. The era of open innovation. Sloan Management Review, Spring; 35-41; Nobelius, D. 2004. Towards the sixth generation of R&D management. International Journal of Project Management, 22(5): 369-375; Rothwell, R. 1994. Towards the fifth-generation innovation process. International Marketing Review, 11(1): 7-31.

First and second generations of innovation

Reviewing the progression of the management of innovative projects from the first to fifth generation processes, Rothwell (1994) showed that the early models of the engineering paradigm were based around a simple linear technology push and needs pull. This is represented by the models of Carter and Williams (1957) and of Myers and Marquis (1969). The former i.e. technology push was defined as that, from the 1950's to the mid 1960's the industrial innovation process was generally regarded as a linear process, starting with scientific discovery and moving through technological development within the firm, culminating in a delivered product to the market place. This was defined as the first generation of innovation. Under this concept, sciences and technologies would drive change in the market place; however, the role of transformation processes and market effects were largely ignored. The latter i.e. needs pull was seen during the period from the mid 1960's to early 1970's. It brought a greater emphasis upon demand side factors, as highly efficient companies fought for market share, the market began acting as the initiator creating new needs which the firms then met through innovation, termed as the second generation of innovation. The biggest danger of the needs pull model was that the constant adaptations to market needs could lead companies to neglect long-term innovative projects (e.g. pre-discovery) and become locked into a regime of technological incrementalism. Hence, they lost the ability to adapt to any radical market or technical changes that occurred (Hayes & Abernathy, 1980). However, it was later argued that these two generations were "over-simplified, extreme and atypical examples of a more general process of coupling between science, technology and the market-place" (Rothwell, 1992, p. 222).

Third generation innovation

The period of the 1970's, with two major oil crises, was marked by high rates of inflation and demand saturation (Rothwell, 1994), i.e. the supply capacity generally outstripped demand. Companies were forced to adopt strategies of consolidation and rationalisation, with a growing emphasis on scale and experience benefits, which were associated with the concerns about accountancy and financing matters. Thus, strategic focus on cost control and cost reduction became the key themes of this stage (Miller & Morris, 1998). Having encountered severe resource constraints, it became increasingly necessary to understand the factors inherent to successful innovation. This has been reinforced by the realisation that the 'technology-push' and 'market-pull' concepts have not sufficiently explained the innovation process during this period (Cooper, 1983; Cooper & Kleinschmidt, 1987; Mowery & Rosenberg, 1978; Rothwell, 1994; Utterback, 1971). Instead, a portfolio-aspect and interactive, or so called 'coupling', innovation process has been built up, termed as the third generation innovation (Rothwell, 1994). This process can be regarded as:

> *"…a logically sequential, though not necessarily continuous process, that can be divided into a series of functionally distinct but interacting and interdependent stages. The overall pattern of the innovation process can be through of as a complex net of communication paths, both intra-organisational and extra-organisational, linking together the various in-house functions and linking the firm to the broader scientific and technological community and to the marketplace. In other words the process of innovation represents the confluence of technological capabilities and market-needs within the framework of innovating firm." (Rothwell & Zegveld, 1985, p. 50)*

Whilst third generation innovation became more linked and interaction focused than the previous two generations of innovations, it was still essentially a sequential process, with feedback loops (Rothwell, 1994). That is, this process was rarely associated with performing one or two tasks brilliantly, but with conducting most tasks competently in a balanced and well co-ordinated manner. Figure 2.2 illustrates this coupling innovation process.

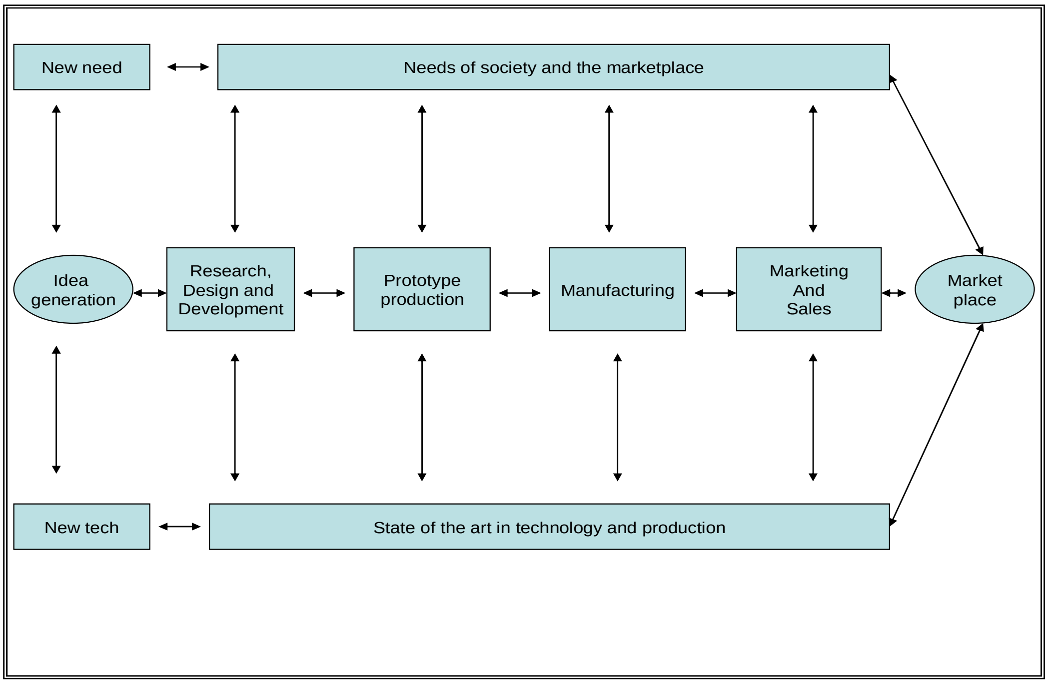

Figure 2.2: The Coupling Model of Innovation (Third Generation of Innovation)

(Source: Rothwell, R. 1994. Towards the fifth-generation innovation process. International Marketing Review, 11(1): 7-31, p. 10)

In the coupling model, the iteration between adjacent activities (e.g. design and engineering) has been criticised for creating inefficiency in the process, through the focus on functions within a firm (Hayes, 1988). Ideally, there would not be any iteration – issues would be resolved with full consensus between all those in the model at the first attempt. The models that succeeded the coupling model sought to eliminate these downside elements, with the most recent treating any re-handing of information as a waste. This is the model considered by Gopalakrishnan and Damanpour (1997), in which they considered that there are clear demarcations between R&D and the rest of the organisation. As will be discussed later, practices for managing innovative projects have moved on from this coupling model.

Fourth generation innovation

During the early 1980's, companies began to focus on core business and core technologies (Peters & Waterman, 1982). Shortening product life cycles meant that speed of development had become progressively more important and companies increasingly focused on technology and manufacturing strategies (Rothwell, 1994). In this period, it has been found that the performance gap between Western and Japanese manufacturers was not only caused by the technological limitations. Moreover, the specific features of the Japanese new product development (referring to innovative projects) system enabled them to innovate more rapidly and efficiently than their Western counterparts (Nonaka, 1991; Sobek II, Liker, & Ward, 1998; Ward & Liker, 1995). The Japanese model of new product development was comprised of two main features – integration and parallel development processes. The former meant that innovating companies integrated suppliers and the different in-house departments into the system at an early stage; the latter meant that those involved worked on the projects in parallel, rather than sequentially. The integration and parallel development processes formed a so-called 'rugby' approach to new product development (Imai, Nonaka, & Takeuchi, 1985). Figure 2.3 illustrates an example of this innovation process, which has been practised in Nissan.

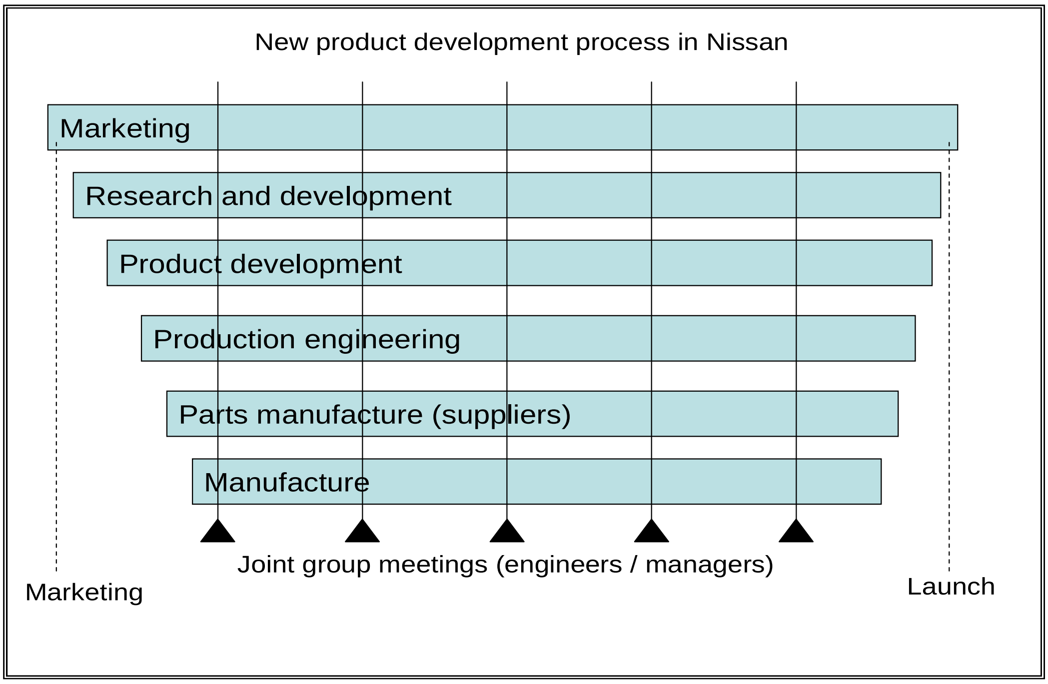

Figure 2.3: The Fourth Generation Innovation Process

(Source: Rothwell, R. 1994. Towards the fifth-generation innovation process. International Marketing Review, 11(1): 7-31, p. 12)

Integration takes place between the stages of the process (e.g. between design, engineering, manufacturing and marketing) and the role of both customers and suppliers in the process are recognised (Hines, 1993). The integration remains fairly horizontal with innovative projects still regarded as functional rather than strategic activities. The major difference between this and the third generation innovation processes is the recognition that significant benefits could be gained from changes in the scheduling of activities, i.e. the move from sequential to parallel processes of undertaking innovative projects. This was aided by changes in design technologies. For example, in the biopharmaceutical sector there has been major improvement in linkages between computer-aided-design (i.e. simulation of bio-molecular activities) and the efficiency of new drug development processes (Pisano, 2006). Suppliers represent another key area where such integration has been beneficial. For instance, the publication of the reports of Japanese firms' integration with suppliers was significant in encouraging the development of the cutting/forming machines industry in the UK and other Western firms (Hines, 1993; Twigg & Voss, 1991). Moreover, Johnsen et al. (2006) suggested the involvement of suppliers in the later stages of the innovation life cycle may play an important role in the success of innovation. In addition, if such relationships are formed at the pre-discovery stage of the innovation cycle, they would enhance its efficiency and effectiveness. This is because nowadays scientific and technological breakthroughs, which are mostly supplied by knowledge production organisations (e.g. universities), are highly associated with creating novel products, and improving the innovative effectiveness of a firm in the high-tech sectors (e.g. information technology and biotechnology industries) (Auderetsch, Link, & Scott, 2002; Belderbos, Carree, & Lokshin, 2004; Khilji et al., 2006; Nobelius, 2004; Oliver, 2001, 2004; Tether, 2002). However, projects established in the pre-discovery stage were still suffering from low efficiency and effectiveness.

Fifth generation innovation

Rothwell (1994) reported that most leading companies in the early 1990s continued to adopt many of the strategy trends established during the 1980s, which were of importance in that period. These strategies still used were comprised of: technological accumulations (technology strategy); strategic alliances; speed to market (time-based strategy); striving towards increasingly better integration of product and manufacturing; seeking greater flexibility and adaptability; emphasising quality and performance features. Amongst these, 'speed to market' is perhaps the one that has attracted most attention during the period, as being first to market with new products or services is more likely to provide a number of advantages, e.g. greater market share and increased customer satisfaction (Reiner, 1989), which certainly profit those who introduce new products or services earlier than others.

However, time and cost are a trade-off during the process of conducting innovative projects (Mansfield, 1988), indicating that seeking a balanced relationship between these two factors has become a critical factor related to the success of an innovation and to making a profit. Therefore, innovation processes were likely to be directed towards even faster development speed and greater efficiency. Rothwell (1994) argued that based on several studies (e.g. Clark & Fujimoto, 1989; Mansfield, 1988) leading innovators adopted a variety of practices for reaching an optimum relationship between time and cost, during the new product development process. These practices included internal organisational features, strong inter-firm vertical linkages, and external horizontal linkages. By doing so, organisations were able to share heavy technology investments with their external partners and learn internal and external knowledge from their in-house departments and strategic partners (Powell et al., 1996). This resulted in a shift towards a novel innovation process, a process of system integration and networking (SIN), also named as the fifth generation innovation process (Rothwell, 1994). Figure 2.4 illustrates an example of this.

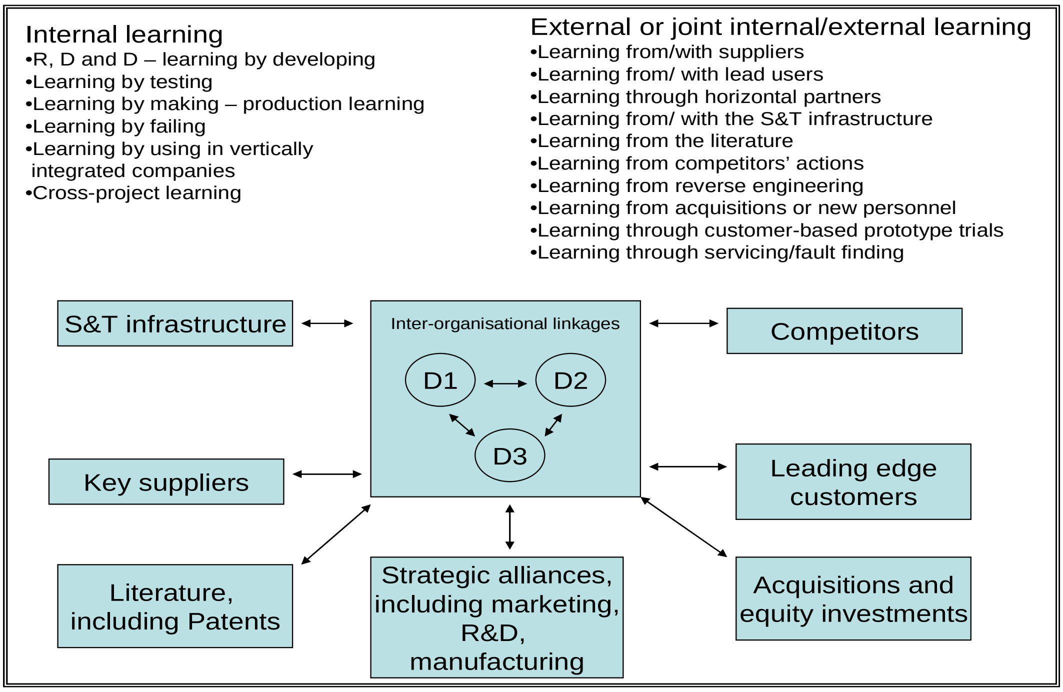

Figure 2.4: The Fifth Generation Innovation as a Process of Know-How Accumulation

(Source: Rothwell, R. 1994. Towards the fifth-generation innovation process. International Marketing Review, 11(1): 7-31, p. 27)

Innovative projects therefore needed to interact with all relevant parties (e.g. competitors, distributors, customers, suppliers, etc.) in the environment. In order to interact with them properly, they needed to place more emphasis on the ability to coordinate and integrate the system. In addition, it was not only necessary to enhance the speed of product development, but also to control it, as time to market was in greater focus than ever before. Based on this logic, the central theme of innovative projects during this generation has been apparently to strengthen the need for the efficient and effective integration of a coherent network, and meanwhile to reduce the uncertainty resulting from it. One common approach to reducing such uncertainty has been to try to keep the research away from the development (MacCormack, Verganti, & Iansiti, 2001; Nobelius, 2004), which has happened at computer hardware and software companies, such as the Microsoft and Dell Corporations.

Drawing from the fourth and fifth generation of innovations, the efficiency, effectiveness and success of innovation cycles are more likely to be dependent on cooperation with several outside parties, e.g. supplier, customers, competitors. In addition, collaborating with different parties would have different effects on the innovation cycle. For instance, collaborations between innovating firms and universities are mostly the domain of firms pursuing radical innovations, rather than incremental forms (Tether, 2002). However, cooperating with customers is more likely to be associated with incremental innovations (Belderbos et al., 2004). As a result, the levels of efficiency and effectiveness of innovative projects, during the pre-discovery stage, should be seen as important to the overall success of an innovation cycle. In general, this pre-discovery stage primarily concerns the projects, in which university scientists are involved in, and is the focus for this study. The involvement of university scientists, one of the key suppliers of knowledge and technologies in the cycle, occurs at this pre-discovery stage, and should be of paramount importance for successful project delivery. This work will concentrate on this pre-discovery stage, for as can be seen what happen during this stage is crucial to the overall cycle outcome. However, the management approaches being adopted by the key players, i.e. university scientists in the innovative projects established at the pre-discovery stage of innovation cycle, are still under researched.

2.1.4. Structure of Innovative Projects

In the light of the evolutionary perspective of the innovation process, it can be seen that it has become more complex and integrative, and since the time of the late 20^{th} century, it has shifted from a ‘closed innovation model’ to an ‘open innovation model’, in terms of the rigidity of boundary barriers to the innovation sources and to the markets (Chesbrough, 2003). Thus, companies, even large and leading ones, have gradually started commercialising innovations from both in-house and outsiders, resulting in not just focusing on the boundary in which their current business markets have existed, but seeking chances to create new markets outside of the industry boundary (Powell, White, Koupt, & Owen-Smith, 2005). For instance, in the biotechnology industry, it has been reported that major discovery and innovation has happened in collaborations between universities and small and medium-sized biotechnology firms (e.g. Powell et al., 1996; Zucker & Darby, 1997), i.e. mostly outside of the big companies (e.g. Audretsch & Stephan, 1996; Oliver, 2004).

Therefore, this may result in more university scientists being persuaded to become involved in UICs, and for universities to become more integrated into the innovation and economic system (Cohen et al., 1998; Cohen & Levinthal, 1990; Dasgupta & David, 1994; Etzkowitz, 1998; Lee, 2000; Mansfield & Lee, 1996; Pavitt, 1991, 2001). Innovative projects being undertaken by university scientists can be simply divided into two structures. One structure is individual projects, and the other is collaborative projects, referring to academic and commissioned innovative projects, respectively. This is because academic projects are usually characterised by: lower pressure on tangible results and deadlines than commissioned ones, by a structure that favours individual work rather than team-work, and by results that are far more distant in time. On the other hand, the commissioned projects tend to be organised as a work package that can be formally identified, thus favouring several team members' participation. In other words, in commissioned innovative projects, many people belonging to different functional areas (e.g. development, marketing, production) are put together into multi-functional teams to accomplish pre-stated objectives. By contrast, academic innovative projects are mainly organised as individual projects (Chiesa & Frattini, 2007; Chiesa, Frattini, Lazzarotti, & Manzini, 2007).

The structures of innovative projects that university scientists are involved in are highly likely to influence the management approaches employed in these two kinds of endeavours. For example, Maylor (2001) reported that employing PM practices is one of the key elements in managing integrated innovative projects, and such employment can provide benefits. In addition, the structure can influence the selection of the dimensions of performance measurements, leading to the employment of different managerial approaches to managing innovative projects, because these measurements are seen as one of vital project management tools (Chiesa & Frattini, 2007). In fact, it has been revealed that university scientists may employ PM practices when they are involved in collaborative innovative projects, which are most likely to be considered accountable in terms of their efficiency, effectiveness, internal and external customer focus and alignment to firms' business strategies (Bremser & Barsky, 2004; Kumpe & Bolwijn, 1994; Pearson, Nixon, & Kerssens-van Drongelen, 2000). By contrast, individual innovative projects, are concerned with effectiveness; the quality of their scientific and technological results is far more critical than the time needed to obtain them and the required resources maybe not limited (Cohen et al., 1999b; Omta, 1995; Roussel et al., 1991). Consequently, different structures of innovative projects may lead university scientists to manage innovative projects using different managerial approaches.

2.1.5. Purpose of Innovative Projects

As shown, the innovative projects within the boundaries of this study are highly integrated into the innovation cycle, and more likely to be undertaken to provide new products, including knowledge, technologies and processes. In addition, innovative projects in the pre-discovery stage are established for basic research, and invention and innovation. As a result, projects within the framework of this study are most likely to be for different purposes. In order to understand whether the different purpose of these projects would influence the management processes employed, there is a need to distinguish between them.

Process innovation tends to refer to innovation in production or manufacturing processes (e.g. Utterback & Abernathy, 1975; Wheelwright & Clark, 1992). It is traditionally seen as independent from product innovation. However, in reality, these two innovations are difficult to separate from each other. Not only are these two correlated (Freeman, 1994), but also they are dependent on the perspective (Biemans, 1989). For example, R&D people may see 'biochip' as a process innovation whereas medical examination departments may view it as an innovative product. Combination of product and process innovations have been termed as 'technical innovation' (Utterback & Abernathy, 1975) or 'technological innovation' (Tidd et al., 2005). It has been argued that process innovation is driven by either the improvement of technology or the reduction in costs of product development. However, the driving force may not always be the technology-push case (e.g. Freeman, 1987); furthermore, process innovation, it has been argued, has to be right from the start of product launch (e.g. Pisano, 1997; Wheelwright & Clark, 1992).

Whilst the definitions presented above are usually employed to define the innovativeness of products, such concepts can be applied to distinguish the innovative project in terms of their innovativeness, because: “innovations are projects which are distinguished not only by the promise of reward they offer, … but also by the risk and uncertainty that accompanies [sic] their potential outcome” (O'Connor & McDermott, 2004, p. 11). In addition, process innovations are often driven by the outcomes of basic research. Thus, the typology of innovative projects can be based on the degree of innovativeness of product or process. Hence, innovative projects at the pre-discovery stage of the innovation cycle can be defined as radical or incremental innovative projects. Moreover, in accordance with their outcomes, the radical innovative projects are usually seen as basic and applied research projects, and the incremental innovative projects are usually defined as developmental research projects (OECD, 1980; Roussel et al., 1991).

This view may be not sufficient to classify the innovative projects within the boundaries of this study, as such projects are not always designed for the purpose of the innovation cycle, and several factors should be considered for their classification. Regarding the purpose, basic research may not be seen as radical process innovative projects. For example, in the post ‘Human Genome Project’ (HGP) era, technologies employed to any project for the identification of the gene map of any living organism are usually not innovative ones, as most of them have been employed in the HGP. In addition, other factors could be associated with their classification, for instance, the degree of uncertainty (Turner & Cochrane, 1993), as will be discussed later. In terms of the degree of uncertainty, innovative projects can not to be simply divided into two groups (i.e. radical vs. incremental). Taking this into account, it would be better to categorise innovative projects as basic, applied and developmental research. For example, based on the OECD (1980), as will be presented in detail later, basic research is to discover new knowledge without any pre-setting, in which goals and methods are extremely difficult to define, in line with Turner and Cochrane’s type four project; however, applied research is undertaken towards a specific practical area or objectives, that is its object can be defined, in accordance with Turner and Cochrane’ type three or two project. This explains the difference between basic research and applied research in terms of the degree of uncertainty and innovativeness. A more detailed description about the characteristics of basic, applied and developmental research projects will be presented below. Table 2.2 summarises these three types of innovative projects, including their purposes, characteristics, degrees of uncertainty and structures.

Table 2.2: Summary of the Classification of Innovative Projects in the Frame of this Study

Purpose	Characteristics	Degree of uncertainty	Structure
Basic research	Extending the boundaries of existing knowledge	Extremely high in terms of defining both project objectives and methods; the highest amongst these three types of innovative projects	Mostly individual academic projects
Applied research	Seeking the possibility of the application of the outcomes of basic research for a particular purpose	High in terms of defining both project objectives and methods but may be not high in defining objectives; in the middle for these three types of innovative projects	Mostly individual academic and commissioned projects
Developmental research	Producing new products, services or processes for markets	May be moderate in terms of defining methods, generally low in defining project objects; the lowest amongst these three types of innovative projects	Mostly collaborative commissioned projects

It could be agued that basic, applied and developmental research should be seen as the stages in the innovation cycle (see Figure 1.1); however, these innovative projects, particularly basic research projects, are not always designed for the purpose of innovation. Nevertheless, the outcomes of these projects may be applied in the innovation cycle. For example, the discovery of two kinds of biological enzymes, i.e. restriction enzymes and ligase, is the outcomes of basic research designed for understanding the mechanism of gene crossover, which is vital for understanding the theory of gene diversity in the subject of Molecular Genetics. However, owing to the functions of these two enzymes, i.e. the former functioning to slice a gene into fragments, and the latter to re-linking the gene fragments, whereby the manipulation of genes becomes possible. As a result, the application of these two enzymes resulted in the invention of the technique for recombinant DNA (rDNA) that became the basis for genetic engineering (i.e. the initiation of the biotechnology industry) (Cohen, Chang, Boyer, & Helling, 1973; Edwards et al., 2003). As a consequence, innovative projects that university scientists are involved with would be better to be classified in terms of their purposes, based on the OECD's definitions, as will be presented later.

Basic research projects

Basic research is defined as "experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable facts without any particular application or use in view" (OECD, 1980). That is, basic research creates knowledge by searching for empirical evidence to test hypotheses or theories by using scientific methodologies, and its results are mostly published in scientific journals and challenged by colleagues working in relevant fields. Hence, basic research is introduced to extend the current boundaries of knowledge. In terms of the length of time taken from research project to research outcomes, basic research could be a long-term effort, even up to 15 years in the biotechnology sector (Khilji et al., 2006). Whilst basic research can be seen as a radical innovation in the innovation cycle, it is often characterised as a radical innovative project, as its goals, approaches and products are unstructured and uncertain (OECD, 1980; Turner & Cochrane, 1993); moreover, its outcomes may bring radically technological breakthroughs to the existing products/services (Roussel et al., 1991).

Applied research projects

The OECD has defined applied research as "original investigations undertaken in order to acquire new knowledge directed primarily towards a specific practical area or objectives" (OECD, 1980). Applied research is also original research and is carried out either to find out whether it is possible to use the output of basic research activities or to develop new methods or technologies to achieve specific objectives. That is, applied research is an innovative project that seeks the application of the outcomes of science, and is most likely driven by market-oriented forces. As a result, the degree of uncertainty of project goals and product should be lower than for basic research projects (Turner & Cochrane, 1993). Moreover, the products of an applied research project are likely to change either core design concepts or the linking mechanism of existing projects/services (Roussel et al., 1991).

Developmental research projects

Developmental research activities have been defined as "systematic work, drawing on existing knowledge gained from research and practical experience, that is directed toward (a) producing new material, products, and devices, (b) installing new processes, systems, and services, and (c) improving substantially those already produced or installed" (OECD, 1980). Developmental research is concerned with the transformation of the knowledge or technology gained from basic and applied research to improving existing products, processes or services (Roussel et al., 1991); in addition, its level of uncertainty and risk is usually less than in the other research purposes.

The above has added the elements related to the purposes and structures of innovative projects into the initial conceptual framework, shown in Figure 2.5 below.

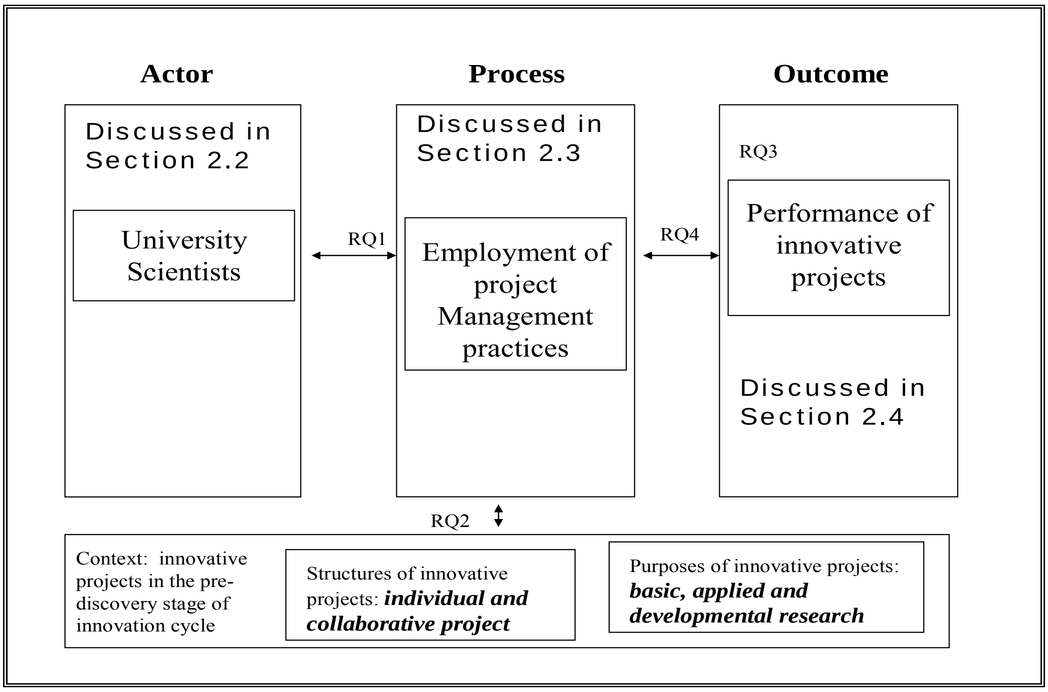

Figure 2.5: Initial Framework Integrating the Elements of Structure and Purpose of innovative projects

2.1.5. Formulating Research Question 2

It has been argued that it is not clear yet whether the best PM practices associated with incremental innovative projects would also apply to radical innovative projects, as some of those used in incrementally innovative projects may be counterproductive, when applied to the radically innovative projects (Leifer et al., 2000; Veryzer, 1998). In other words, the projects that feature a high degree of innovativeness (i.e. basic and applied research) may require a different management approach than that used for incremental or moderate innovations (i.e. developmental research) (Salomo et al., 2007; Song & Montoya-Weiss, 1998). Moreover, some university scientists have argued that using PM practices may be harmful to the effectiveness of individual projects and their creativity (Cohen et al., 1999b; Miller, 1986). For example, project monitoring and controlling at the project level continue to be one of major tools for keeping collaborative projects on schedule, within budget, and aligned with strategic objectives (Cooper & Kleinschmidt, 1995). However, the critical question in the context of individual (academic) projects is the frequency of project monitoring and controlling activities, that should be exercised to keep the projects on track, whilst avoiding dysfunctional effects, or unwelcome surprises (Brown & Eisenhardt, 1997). The structure and purpose of innovative project are known to make a difference, and a few empirical studies have systematically investigated the effect of these two on the employment of PM practices (Shenhar, Tishler, Dvir, Lipovetsky, & Lechler, 2002; Song & Montoya-Weiss, 1998). However, it is difficult to find a common denominator of such an effect, and in some cases the findings are entirely contradictory. For instance, Shenhar et al. (2002) revealed that the employment of PM practices is especially important for complex projects involving high uncertainty, but Song and Montoya-weiss (1998) found these practices can be counterproductive for such projects. Thus, it is worthwhile to explore whether the structure and purpose of innovative projects influence the level of employment of PM practices by university scientists, and therefore gain a better understanding of how they manage such work. Thus, the Research Question 2 stated in Chapter One is formulated:

- RQ 2: how do the structure and purpose of innovative projects impact on the use of PM practices (Process) by university scientists (Actor)?

2.2. Actor (University Scientists)

In general, it may be expected that scientific and technological factors mostly contribute to the failure of UICs established in science-based industries, e.g. the biotechnology industry, because those sectors are characterised by a high degree of scientific, technological and environmental uncertainty. However, drawing upon survey data from 83 UICs formed and terminated in the biotechnology sector between 1980 and 1996, Pangarkar (2003) analysed the factors regarding the failure of those UICs, and found that less than 17% of these were linked to the scientific obstacles. Moreover, Pangarkar argued that several other different causes, which may be broadly termed as management issues, accounted for the remaining 83%. These empirical studies argued that UICs were likely to require the greatest amount of biotechnology firms' management effort and capability, because the key to successful collaboration lies the way in which they are managed (Dodgson, 1993), and that the differences between non-profit and for-profit organisations tend to be more fundamental than those between the various types of for-profit organisations (e.g. Amabile et al., 2001; Gomes, Hurmelinna, Amaral, & Blomqvist, 2005; Lane & Lubatkin, 1998). In addition, university scientists are usually the key players in the process of undertaking UICs (Pisano, 2006); therefore, there is a need to understand how they behave in the management of innovative projects, with a view to improving their management (Sapienza, 2005). Some literature (e.g. Cohen et al., 1999a; Cohen et al., 1999b; Mason, 1979; Miller, 1986; Sapienza, 2005) has been published to address the issue, and has pointed out that the behaviour of the scientists working in the academic sector is different from those who are working in industries. Table 2.3 provides an overview of these differences.

Table 2.3: Major Difference in the Behaviour of Scientists in Academic and Industries

Academic	Industry
Research is the right place for a *prima donna* (individual) works	Usually organised as teamwork
Reward mostly on qualitative output	Avoidance of people spending much of their time moving the process along
Usually connecting to other scientists in the same environment	Avoidance of people with pure science credentials
Opportunities to present their work to peer review committees	Recruitment of people who can manage across corporate functions
People with a long term scientific perspective	People with a broad perspective (business implications for scientific results)
Look for public recognition, professional status, academic career	People with a short term business perspective
	People with an entrepreneurial spirit (winning attitude)

(Source: adapted from Chiesa, V. & Frattini, F. 2007. Exploring the differences in performance measurement between research and development: evidence from a multiple case study. R&D Management, 37(4): 238-301. P. 287)

In accordance with Sapienza (2005), effective management of projects undertaken by scientists appears to have encountered several difficulties. These difficulties are attributed to, firstly, the purpose of the work is to generate knowledge and ideas and this leads to difficulties in predicting and measuring outcomes (Chiesa & Frattini, 2007; Terziovski & Morgan, 2006). Secondly, university scientists' academic education and training directs them towards forming their own conceptual framework, vocabularies, and discipline cultures (e.g. highly trained solo contributors). Finally, university scientists, like all other human beings, have modes, biases and quirks. Taking these characteristics and the nature of science (e.g. an oblique and unpredictable activity) into account, previous theories regarding the management of research and development (R&D) may not be appropriate for managing the innovative projects carried out by university scientists.

Based on the management of R&D in general from the academic side, Mason (1979) conceptualised science as a system of knowledge production; that is, as a series of activities or tasks which collectively produce research conclusions. The sequence of these scientific activities is generally as follows: the university scientists must (1) get a good idea, (2) design a research project to secure relevant evidence, (3) acquire the necessary resources to complete the project, (4) organise the resources to make best use of them in conducting the research, (5) actually perform the research, and, finally, (6) produce conclusions to be assimilated into the corpus of knowledge.

Mason (1979) viewed science as a unity of opposing forces. One of these forces is represented by the ideal of science as the dispassionate and unconstrained quest for truth. This ideal is both challenged and supported by another potent force; that is, the managerial ideal of the efficient use of resources in the pursuit of goals. He concluded that the concept of management is necessary to science, but also contrary to science. This conclusion would go against the university scientists' mentality. Indeed, drawing from the literature, it would appear that the absence of management intervention, in the context of innovative projects, has been found to be desirable from their perspective (e.g. Cohen et al., 1999a; Cohen et al., 1999b; Miller, 1986; Sapienza, 2005). This may be based on the fact that they see themselves as knowledge workers, usually bringing unique values and expectations to their workplaces and that they are usually achievement-orientated individuals who seek motivation from the work itself (Sapienza, 2005). Thus, they usually consider themselves to be self-management individuals. As a consequence, a high level of autonomy in managing their innovative projects is important to them, and they are increasingly sensitive to the quality of the work environment, climate, and culture, resulting in the situation that self-management has become almost synonymous with being professionals (Miller, 1986). However, from their point of view, such self-management consists of not only managing an innovative project, but also there is a scientific agenda (Cohen et al., 1999b; Sapienza, 2005).

Recently, the management of innovative projects carried out by university scientists, has moved towards more accountability than ever before, as these such projects have gradually become more visible, in particular, in terms of their contribution to the national economic system (e.g. McMillan et al., 2000; Pavitt, 2001). Consequently, university scientists have encountered the pressure of ensuring the maximum value of their innovative projects, and have been integrated into an environment which is more market-orientated than it have been previously (Cohen *et al.*, 1999b). In fact, some of them have demonstrated that management has placed increasing emphasis on quantifiable measures, regarding particular project aims, i.e. commissioned work, and on association with other stakeholders. However, the responses to this emphasis are varied. Whilst some university scientists have seen it as helpful for improving efficiency, others have acknowledged that it as a barrier to the effectiveness, autonomy and creativity (Cohen et al., 1999b; Miller, 1986; Turpin et al., 1996).

Based on the discussions presented in this section, it can be seen that there are no commonly agreed management practices employed by university scientists, and it appears that they are likely to adopt different approaches, depending upon the type of structures and purposes of innovative projects. That is to say, the exploration of how university scientists manage innovative projects should not be limited to how they manage collaborative (commissioned) innovative projects and attention should also be paid to how they manage individual (academic) projects. In addition, as mentioned, the management adopted by university scientists may be influenced by outsider stakeholders (e.g. industrial collaborators). Hence, there is a need to investigate the industrial managers' point of view, and then cross verification can be proceed to increase the reliability of the data gathered from university scientists (Bryman, 2001). Thus, two elements of the 'actor' construct – university scientists and industrial managers– are integrated into the initial conceptual framework (Figure 2.6).

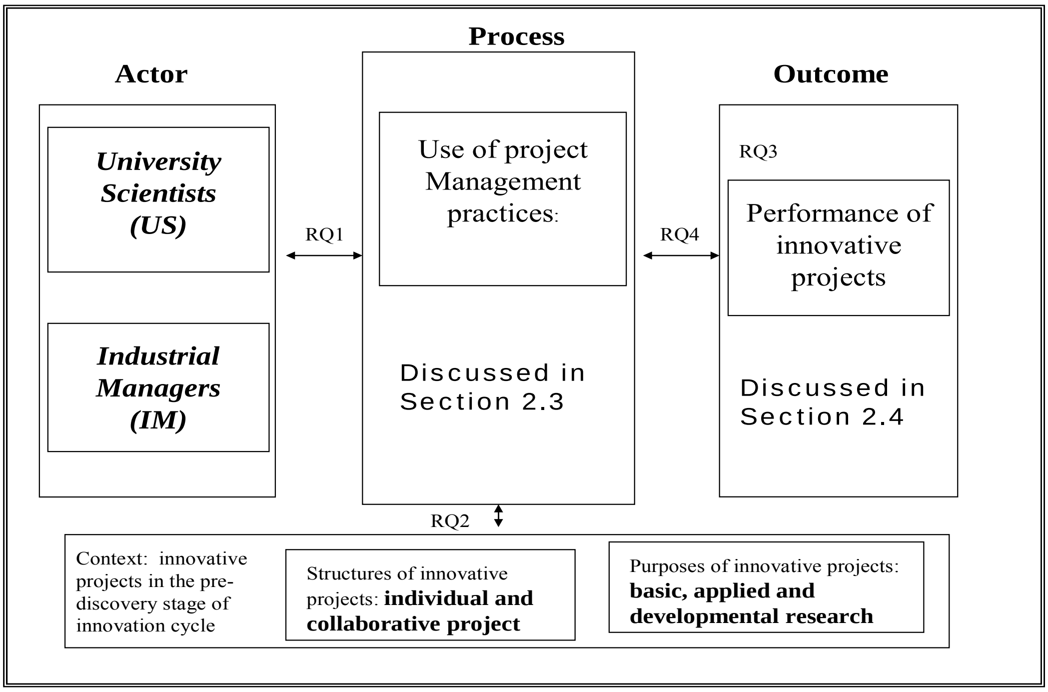

Figure 2.6: The Initial Framework Incorporating the Elements of the Actor Construct

In addition, regarding university scientists, industrial managers, management practitioners and theorists, there is no consensus either within or between these groups as to whether the pursuit of managerial ideas detracts from and/or constrains the pursuit of scientific ideas. However, managerial ideas must be nourished and preserved. Following on from this, this researcher argues that it is time to explore how university scientists manage innovative projects, and how this impacts on the management of project performance. This sets out the objectives of this study, and the motives for the research questions stated in Chapter One. As PM theory has been chosen as the approach for this study, the research questions towards the objectives from the PM perspective will be identified in the discussion below.

2.3. Process (Employment of Project Management Practices)

Theory regarding the management of innovative projects is a well developed discipline, which has been covered in a wide range of literature. It started with the early studies of Burns and Stalker (1961) that introduced a classical distinction between incremental and radical innovations. And it continues today with varying points of view and the lessons that have been applied to real organisations. Studies have related to the process of innovation, structural, architectural and system innovation, cultural innovation, and the theory of managing disruptive technologies (e.g. Anderson & Tushman, 1990; Brown & Eisenhardt, 1997; Christensen, 1997; Gatignon, Tushman, Smith, & Anderson, 2002).

The traditional concept of managing innovative projects has been: the bringing together of brilliant scientists, providing them with the best facilities and with abundant resources (e.g. Keegan & Turner, 2002) where there is the highest degree of autonomy (e.g. Miller, 1986). Then there is a wait for significant breakthroughs. For example, Hamel and Pralahad stated "…put a few bright people in a dark room, pour in some money and hope that something wonderful will happen" (Hamel & Pralahad, 1989). An inspiring example of this concept of managing an innovative project has been given by Maddox (1988) in the field of theoretical physics. In fact, this strategy is still very common in industrial R&D (Roussel *et al.*, 1991). It is no doubt that good scientists are necessary for success, but good researchers are insufficient for achieving it (Omta & de Leeuw, 1997). Considerable literature on the management of innovative projects has expressed that just bringing some good scientists together often ends up in an argument; therefore, recent studies have started with the underlying assumption that management does make a difference between success and failure in research.

Numerous academic papers have been published on different aspects of the management of R&D. Most of them have considered the managerial aspects of industrial R&D (e.g. Tushman & Moore, 1988). They have mainly focused on strategic and operational aspects, such as project selection and evaluation, project planning, human resources management and staffing, and the interfaces with marketing and productions. However, there has been little literature concentrating on the managerial aspects of R&D within the academic world. Omta and de Leeuw (1997) summarised some of the studies from the academic world focusing on: strategic planning, academic research management in general, individual laboratories (Latour & Woolgar, 1979; Mason, 1979), individual leadership (Gilley & Fulmer, 1986), and management and culture in relation to the performance of science (Birnbaum, 1988).

In addition, UICs are difficult to manage (e.g. Amabile et al., 2001; BHEF, 2001; Dodgson, 1992). These difficulties have driven forward research into the identification of management 'success' factors (BHEF, 2001). The following provides some examples concerning 'success factors'. Forrest and Martin (1992) surveyed the R&D partnership of 144 small firms and 70 large biotechnology companies in North America and concluded that the critical success factors were 'agreement on strategic objectives and goals', 'communication, commitment', 'good interpersonal relations', 'compatibility and mutual trust'. A survey conducted in New Zealand (Davenport et al., 1999) showed that practitioners, participating in UICs, pointed out that the five most highly ranked success factors were 'selecting right collaboration partners', 'a clear understanding of each partners' responsibility and tasks', 'common goals with no hidden agendas', 'mutual respect and trust amongst partners', and 'top managerial commitment from all parties'. Barnes *et al.* (2006) found similar factors associated with the success and the failure, after having carried out research into six UK UICs.

On the contrary, Davenport *et al.* (1999) showed that the industrial participants in the New Zealand survey rated 'unclear or unrealistic goals', 'unmet expectations', 'a lack of trust, honesty and openness', 'hidden agendas', 'lack of commitment', and 'lack of communication and misunderstandings between the partners' as the most serious factors causing the failure of UICs. Similar factors were found, from the industrial perspective, in the biotechnology firms in Taiwan (Sun, 2004a). These 'success' and 'failure' factors can be categorised into seven themes – 'choice of partner', 'environmental factors', 'cultural gap', 'project management', 'ensuring equality' and 'universal success factors'; in addition, these themes have been employed as elements of a 'best PM practice' model for managing UICs (Barnes et al., 2006). Moreover, central to these themes would be 'project management', as PM theory is functioning in coordinating every functional group (e.g. marketing, R&D) that is essential to projects in order to facilitate the projects better (PMI, 2004). In addition, these themes influence the managerial approaches adopted by university scientists to manage innovative projects. For instance, Amabile (2001) claimed that the culture gap would lead to different management approaches. Chiesa et al. (2007) stated that the selection of dimensions of performance measurements for innovative projects is affected by the environmental factors, which in turn would affect the adoption of management approaches.

These factors and the best practice model derived from them are mainly from the industrial managers' point of view, because evidence from the university scientists' viewpoint is lacking and thus what would constitute optimal practice for them remains largely unknown. As mentioned, innovative projects established in the pre-discovery stage of the innovation cycle are usually characterised as highly uncertain projects, and such projects have encountered low efficiency and effectiveness. Therefore, it is suggested in this study that PM practices could be appropriately employed to manage such projects, as their usage has been seen to ensure efficiency and effectiveness of projects in spite of all the uncertainty (PMI, 2004). The next section discusses the employment of PM practices in uncertain projects.

2.3.1. Uncertainty

Degrees of uncertainty can be derived from the following, "the state arising from predicting outcomes from the actions taken to achieve them; the more one is able to predict outcomes, the less the uncertainty" (Leblebici & Salancik, 1981, p. 578). The most common definitions concerning uncertainty to be found in the literature are: (1) an inability to assign probabilities to the likelihood of future events; (2) a lack of information about cause-effect relationships; and (3) an inability to predict accurately what the outcomes of a decision might be (e.g. Ashill & Jobber, 2001; Downey, Hellriegel, & Slocum, 1975; Duncan, 1972; Milliken, 1987).

The definitions regarding 'uncertainty' are varied in the literature (Morgan & Henrion, 1990). The common element of the various definitions is the condition of lack of knowledge, or information, experienced by project managers (referring to university scientists). This is to say, a project manager views an element of the project as not definitely known or certain. Such an element could be, for example, a project task that is not accurately predictable. Moreover, Ritchie and Marshall (1993) argued that from a business environment view: "… the state of mind that we term uncertainty can be viewed as arising from each person's imperfect knowledge concerning future events and, as such, it will influence the degree of confidence that the decision-maker has in the decision to be made" (p. 112). Hence, it is suggested in this study that uncertainty is an attribute of university scientists' mental processes as well as one of the physical projects. Therefore, this research will consider uncertainty to be neither purely objective nor purely subjective (Ashill & Jobber, 2001; Morgan & Henrion, 1990).

In the relevant literature, the dimensions of the concept of uncertainty are varied. At project level, projects, for instance, can be categorised into two uncertainty dimensions: goals and method related uncertainty. The former relates to "how well defined are the goals", and the latter to "how well defined are the methods of achieving them" (Turner & Cochrane, 1993, p. 93). According to these two dimensions, four types of project can be defined:

1. Type 1 projects: for which the goals and methods of achieving the project are well defined;

2. Type 2 projects: for which the goals are well defined, but the methods are not;

3. Type 3 projects: for which the goals are not well defined, but the methods are; and

4. Type 4 projects: for which neither the goals nor the methods are well defined.

Further concepts of uncertainty have been posited including those of Lawrence and Lorsch (1967) and Duncan (1972). These have attracted wide attention and have been employed as a basis for further research (e.g. Buchko, 1994; Downey et al., 1975). Lawrence and Lorsch (1967) investigated uncertainty that was related to a specific job in an organisation, whereas Duncan (1972) examined environmental characteristics and their impact on the uncertainty experienced by decision makers. However, these two perceptions appear not to be adequate (Downey et al., 1975). Downey et al. (1975) contradicted Duncan (1972) in arguing that dynamism (i.e. stability of environmental factors) contributes to uncertainty to a greater extent than complexity (interrelatedness of environmental factors). They also criticised Lawrence and Lorsch (1967) for not meaningfully combining their scales of 'clarity of information', 'uncertainty of cause and effect relationships' and the 'time span of definite feedback' to a total uncertainty score (Downey et al., 1975).

Although Downey et al. (1975) considered Duncan's (1972) conceptual framework to be useful, they argued that a key reason for the contradictory results was the inappropriate multi-dimensional conceptualisation of uncertainty (Buchko, 1994; Downey et al., 1975; Milliken, 1987). Building on previous research, Milliken (1987) suggested three uncertainty dimensions – state uncertainty, effect uncertainty and response uncertainty – that have drawn wide attention in uncertainty and project management literature (Ashill & Jobber, 1999, 2001; Buchko, 1994; Ward & Chapman, 2002).

State uncertainty is likely to arise when initial estimates, e.g. regarding cost and quality, are not well specified or are perceived to lack certainty in their planning (Clawson, 1996; Valentine, 1991). Project managers (referring to university scientists) will encounter state uncertainty when they perceive a project environment or component of the project management as being not fully understood or predictable. Effect uncertainty describes the uncertainty that results when "rather than being confident that "given X, then Y", an individual is unable to derive a causal statement" (Milliken, 1987, p. 137). In the context of the innovative projects in the research frame, effect uncertainty may describe the university scientists' lack of information about the impact of a future event, e.g. scientific breakthrough, on the project objectives. In drug development projects, an example of effect uncertainty may be the unknown effect of the clinical trial on the development the drug (i.e. the project objective) (e.g. Khilji et al., 2006). Response uncertainty describes the lack of knowledge, or information, a project manager, i.e. a university scientist, has about his response alternatives and their possible consequences on the environment (Milliken, 1987). It is conceivable that a project manager might perceive response uncertainty, although the effect of an event on project objectives is identified. For instance, decisions about utilising a 'molecular-scanning' approach in a drug development project, may be taken without predicting whether this is the most beneficial step or what consequence this response may have on project objectives such as time, cost and quality (e.g. Khilji et al., 2006).

In a recent study, which synthesises other early work by Duncan (1972), Lawrence and Lorsch (1967) and the revision of the uncertainty concept by Milliken (1987), Ashill and Jobber (1999) argued that particular environmental characteristics to influence uncertainty have been well established in the literature. Moreover, as has been discussed, the different purpose and structure of innovative projects are most likely to introduce uncertainty at different levels; these phenomena appear to influence the approach to managing such projects.

2.3.2. Project Management Practice

Regarding the function of PM, it has the purpose of initiating, planning, executing, monitoring and controlling, and closing activities so that the project is completed as successfully as possible, in spite of all the uncertainty (PMI, 2004). There are various standards in project management, but the most dominant are the best practice standards of the Project Management Institute (PMI). The PMI offers a standard that is widely used and is considered to be a competency standard (Cleland & Ireland, 2002). The PMI standard “A Guide to the Project Management Body of Knowledge” (PMIBOK) (PMI, 2004) includes nine areas of project management knowledge:

Project integration management related to the process of ensuring that various elements of the projects, such as project plans, are coordinated. It includes tasks such as the documentation of the actions necessary to define, prepare, integrate, and coordinate all subsidiary plans into a project management plan.

Project scope management is primarily concerned with the definition and controls about what will or will not be included in the project. It relates to the planning, definition and verification of the scope of the project.

Project time management is composed of the process stages which are required to ensure the timely completion of the project. It encompasses activity definition, activity sequencing, and estimation of the activity duration, schedule development and schedule control.

Project cost management supports the project manager in completing a project within the approved budget, including the three activities of cost estimating, budgeting and controlling.

Project quality management ensures the project’s success in meeting quality targets, focusing on quality planning and assurance, and quality control.

Project human resource management includes the processes such as the human resource planning necessary to effectively use the individuals in the project. Individuals can be project stakeholders such as sponsors, partners, sub-contractors and customers.

Project communication management provides processes to ensure effective communication, in terms of establishing critical links between individuals that are important for project success.

Project risk management is a systematic process which includes the identification, analysis and response to project risks.

Project procurement management involves the processes of determining what to purchase or acquire and determining when and how.

Overall, PMIBOK suggests nine key processes for ensuring the successful completion of a project during the stages of initiating, planning, executing, controlling and closing the project. Each key process consists of several sub-processes. These are well-established processes in the management of projects in an environment, which is seen as relatively certain and structured. Moreover, these processes are primarily concerned with defining and controlling what is or is not included in the projects. That is to say, PM practices are concerned with defining project objectives and the processes that are required to successfully deliver them (PMI, 2004).

Although PM practices for those projects with a low degree of uncertainty have been well established, such establishment for projects with a higher degree of uncertainty (Turner & Cochrane, 1993) may be not appropriate. Hence, projects whose characteristics are highly uncertain could need alterative ways to define these goals and methods. Kerssens-van Drongelen and colleagues (Kerssens-van Drongelen & Bilderbeek, 1999; Kerssens-van Drongelen & Cook, 1997) argued that highly uncertain projects, instead, may use project objectives and milestones. In addition, they claimed that these project objectives and milestones could be applied to monitor and control project progress. Andersen (1996) suggested that in such uncertain projects an interactive milestones approach would enhance their effectiveness and efficiency. This has shown that identifying project objectives and milestones, and dealing with these based on the inputs (e.g. results of experiments in the innovative projects), during the project life cycle, are likely to be crucial to the success of innovative projects.

In light of the discussion above, it can be seen that PM theory has been integrated into the subject of the management of innovation. In fact, such integration has been proceeding for over forty years. For instance, Roman (1964) argued that innovative projects being carried out in industries should be managed, in order to prevent expensive professional workers “go[ing] off on unrelated tangents and bury[ing] themselves in trivia” (p. 19). He suggested that developing project plans and ‘work logs’ in advance is a possible way to avoid this and more likely to lead innovative projects meeting their project objectives within the proposed time-spans and budgets. Nowadays, such concepts are still employed in high-tech companies, e.g., pharmaceutical companies (Schmid & Smith, 2002). During the period of the second innovation generation, PM was introduced to direct and monitor innovative efforts happening in industrial sectors (Roussel et al., 1991). Third innovation generation started emphasizing the importance of PM techniques to improve the efficiency of projects (Roussel et al., 1991), as cost control and cost reduction were the central theme at this time (Miller & Morris, 1998). More recently, during the fourth and fifth innovation generations, PM practices have been heavily employed in managing innovative projects, as these projects have focused much more on coordinating integrated systems, in order to gain the ability of being rapid in product development (e.g. Iansiti & West, 1997), and to control the speed of the accomplishment (Miller & Morris, 1998; Rothwell, 1994). Although PMIBOK suggests employing these nine key processes can ensure the efficiency of delivering innovative projects towards meeting project objectives within schedule and budget, these PM practices may be inappropriate to employ in managing innovative projects, in which university scientists are involved. This is because these nine key processes may be too broad to be used in such projects, and they are not particularly designed for managing innovative projects, or UICs, which are seen as having high degrees of uncertainty.

As shown, some factors related to the efficiency and effectiveness of UICs have been identified (e.g. BHEF, 2001; Davenport et al., 1999), and some ‘best practice models’ for UICs have been proposed (e.g. Barnes et al., 2006; Peças & Henriques, 2006; Terziovski & Morgan, 2006). Peças and Henriques (2006) proposed an innovative step-by-step procedure for enhancing the efficiency potential of R&D collaboration between universities and small and medium-sized enterprises, in the manufacturing sector in Portugal. This model focused on a relatively rigid workflow to undertake UICs, and its development was based on a more structured environment, compared with the innovative projects in this work.

Terziovski and Morgan (2006) suggested a model to enhance the speed of the innovation cycle in the biomedical industry, through the perspectives of: critical success factors (e.g. articulating a scientific vision, securing an intellectual property web, obtaining seamless funding); performance measures (e.g. financial measures, innovation measures); and practices to be employed (e.g. an industry direction and strategy, commercial advisory services). However, the authors' concern was on the post-discovery stage in the innovation cycle (see Figure 1.1), and they made these conclusions from the data provided by industrial people.

Barnes *et al.* (2006) proposed a 'best practice model' for the success of UICs, by drawing qualitative data gathered from six UICs in the automotive and aerospace industries in the UK. Moreover, this model has been employed in the food and drink industries. It is based on seven key themes – partner evaluation, project manager, cultural gap, project management, ensuring equality, external influences and universal success factors. Each theme consists of several practices, separately placed at different stages throughout the whole UIC life cycle. For example, partner evaluation is placed on partner-related issues, i.e. the beginning of the establishment of the UIC. In addition, project management is assigned at the project set-up and execution stage. Thus, project managers of UICs may strengthen their efficiency and effectiveness by employing more robust practices that enhance strategic, organisational and PM processes.

Having reviewed these three models mentioned above, it is posited that the model proposed by Barnes et al. (2006) should be considered as the adequate baseline for this study. This is based on the following facts. Firstly, this model would allow managers to take appropriate and timely actions to prevent problems before they arise, as it encourages an awareness of the key issues affecting the success of UICs. Secondly, evaluation of the tools has demonstrated some preliminary support for its ability to predict potential weakness and risks. Thirdly, this model was initially developed for effectively managing UICs in the automotive and aerospace sectors and has been used in the food and drink industries, indicating that it is more widely applicable. Finally, the model suggests a dynamic approach for employing these practices in UICs.

However, a weakness of employing this model in innovative projects should be recognised. To date it has been employed in industries where the degree of maturity of technologies and scientific knowledge is high, such as automobiles, food and drink sectors. In comparison, the research context of this study is seen as one of the most innovative environments, in which the scientific knowledge is still seen as immature (Cardinal et al., 2001; Mansfield, 1998; Pisano, 1994). This may lead to that the processes of employing the PM practices in these sectors being different (e.g. Salomo et al., 2007). For example, university scientists would find it easier to define 'clear project objectives' when they are undertaking collaborative (commissioned) projects, than when they are carrying out individual (academic) projects. Thus, this study would like to explore whether this model is employed by university scientists in innovative projects. If yes, how does such use impact on the performance of such projects?

Specifically, as stated, the low efficiency and effectiveness of UICs are usually criticised by university scientists' counterpart collaborators, i.e. industrial people; as a result, this study is focused on the application of the PM practices provided by this model, as these are more likely to enhance project efficiency (PMI, 2004). The PM practices suggested by this model are as follows: 'clearly defined objectives', 'clearly defined responsibilities', 'mutually agreed project plan', 'realistic aims', 'adequate resources', 'defined project milestones', 'simple collaboration agreement', 'regular progress monitoring', 'effective communication', and 'ensuring collaborators deliver'. In sum, section 2.3 has integrated the PM practices into the framework of this study (Figure 2.7), and formulated the Research Question 1 stated in Chapter One:

- RQ 1: to what extent do university scientists (Actor) use PM practices (Process) to manage innovative projects?

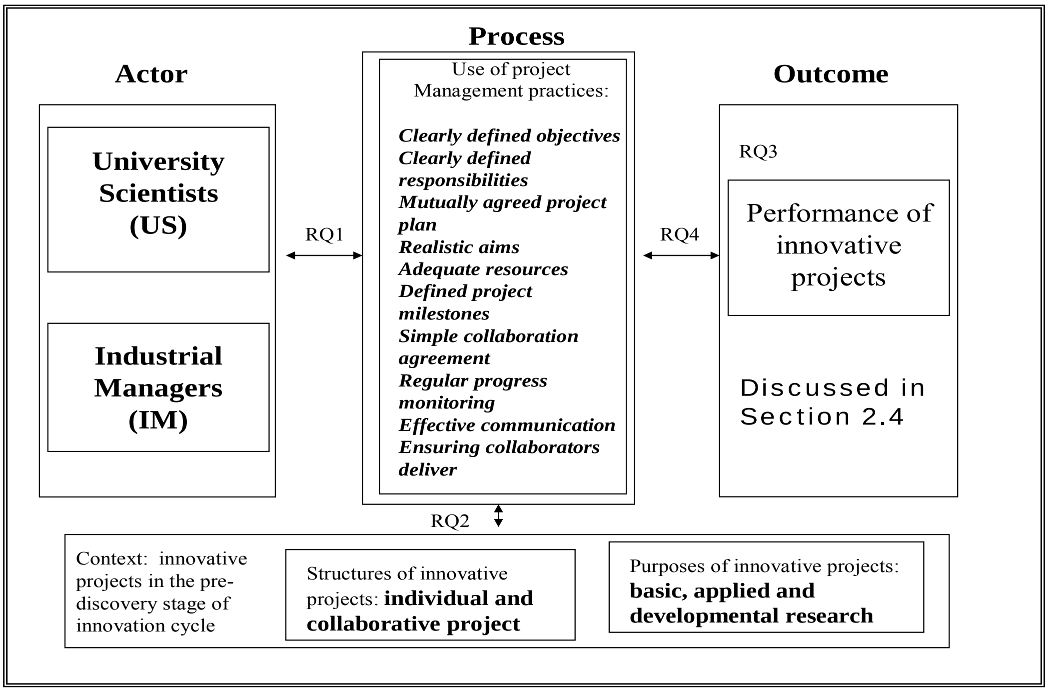

Figure 2.7: The Initial Framework integrating the Elements of Process Context

2.4. Outcome (Performance of Innovative Projects)

The project outcomes of success and failure are, in general, often defined in terms of project managers achieving time, cost and scope objectives. However, project management literature from various fields, such as engineering, has shown that this view is too narrow. Thus, in order to investigate the impacts of the management of innovative projects by university scientists on project performance and what is meant by project performance needed to be explored.

The definition of project success or failure is important in the literature, not least because their measurement has been widely used as the dependent variables in many studies (e.g. Ernst, 2002). However, a review of project management literature provides no single interpretation of project failure or success. Project failure is generally defined as the inability of project managers to meet project goals, time and costs (e.g. Kelly et al., 2002). The British Standards Institute's definition of project management embeds this notion of the pre-eminence of time, cost and quality/scope, by defining project management as the "planning, monitoring and control of all aspects of a project and the motivation of all those involved in it to achieve the project objectives on time and on specified cost, quality and performance" (BSI, 2000, p.10). The criteria of cost, time and scope or quality are often referred to as the Iron Triangle

(Maylor, 2003), which describes that the project's criteria, product scope and quality grade, time-to-procedure, and cost-to-complete are interconnected and cannot change without a corresponding, balancing change, in one or more other criteria.

According to the traditional definition of project success in terms of scope, cost and time, the rate of failure of UICs is immense (Kelly et al., 2002). However, this definition has been criticised (e.g. Atkinson, 1999; Herbertz & Muller-Hill, 1995). For instance, Atkinson (1999) argued:

> *"To date, project management has had the success criteria focused upon the delivery stage, up to implementation. Reinforced by the very description we have continued to use to define the profession, the focus has been to judge whether the project was done right. Doing something right may result in a project which was implemented on time, within cost and to some quality parameters requested, but which is not used by the customers, not liked by the sponsors and does not seem to provide either improved effectiveness or efficiency for the organisation, is this successful project management?"*

Other authors took up this criticism. Wateridge (1995) stated that other success criteria such as the achievement of purpose or stakeholders' satisfaction levels have been neglected. The criticism of measuring project success and failure only when the criteria of scope, cost, and time are met has been highlighted by various other researchers. Wateridge (1995) argued that "… previous research mainly examined the views of industrial project managers and not sponsors or users of the project". He added: "Project managers are putting much emphasis on the time and budget aspects for judging project success at the expense of other criteria" (Wateridge, 1995, p. 171). Baccarini (1999) went further and ranked the criteria of time, cost and performance relative to other objectives: "the project management criteria of time, cost and performance are subordinate to the higher success objectives of goals and purpose" (p. 29). Elkington (2002) concluded that the most important finding of his study was that the cost, time and scope criteria are not the most important, from a project manager's view. He suggested that "by far the most interesting fact is, that despite the success of the project as measure against benefits, time and cost, the manager of the project chose to state that only "some parts (were) successful" (Elkington & Smallman, 2002, p. 55).

2.4.1. Measuring Project Performance

In this section, the literature dealing with the design of performance measurements for innovative projects is reviewed. This will facilitate the construction of a more comprehensive framework for the research. The dimensions (variables) for measuring project performance are various. Considerable literature has highlighted the fact that the choice of the purpose/objectives of the actors in research, is critical in determining the measurements to be used (Bremser & Barsky, 2004; Chiesa & Frattini, 2007; Driva, Pawar, & Kenon, 2000; Kerssens-van Drongelen & Bilderbeek, 1999; Loch, Stein, & Terwiesch, 1996; Meyer, Tertzakian, & Utterback, 1997; Pearson et al., 2000). The objectives that are generally aimed at when performance measurements are applied to innovative projects are shown in Table 2.4.

Table 2.4: Purposes of Performance Measurements for the Innovative Projects

Purposes of performance measures
Supporting decision making
Enhancing the performance of the innovative project
Motivating personnel
Supporting the incentive scheme
Fostering organisational learning
Enhancing communication and coordination
Reducing the risks of the innovative project

(Source: Chiesa, V. & Frattini, F. 2007. Exploring the differences in performance measurement between research and development: evidence from a multiple case study. R&D Management, 37(4): 238-301. P. 285)

There is theoretical and empirical evidence demonstrating that the purposes for which the performance measurements are adopted significantly influence the selection of their constitutive elements (Chiesa et al., 2007; Ojanen & Vuola, 2006). Thus, the identification of the measurement objectives should be considered as a fundamental step in the selection of performance measurements for innovative projects. It is a requirement, regarding the measurements for the performance of innovative projects, that the specific dimensions (variables) to be monitored are adequately selected (e.g. Brown & Gobeli, 1992; Kerssens-van Drongelen & Cook, 1997; Stainer & Dixon, 2003). The choice of the dimensions on the basis of which the performance of innovative projects are assessed is influenced by several factors, such as the firms' business strategies (Griffin & Page, 1996) and the degree of environmental turbulence and uncertainty (Calantone, Garcia, & Dröge, 2003). Furthermore, the level to which the measurements are employed influences the selection of the performance dimensions (Rogers, Ghauri, & Pawar, 2005).

Patterson (1993) suggested that the performance of a project can be evaluated from the economic perspective, that is, its contribution to economic growth after project completion. This is associated with the macro level, such as national or industrial levels, but this is not the focus of this study, which will be concerned with measures related to the micro level, e.g. project level. Pinto and Mantel (1990) identified a few variables for measuring project performance from three stances: the implementation of process; the perceived value of the project; and client satisfaction with the outcomes.

Following Pinto and Mantel's (1990) view, the first dimension is related to project efficiency. From an industrial perspective, efficiency in project management leads to positive results in terms of the short term success (Shenhar et al., 2002), including criteria such as meeting technical specifications, cost and time targets and other pre-stated project objectives. Short term results are a very high priority in industries. However, although the project may have been successfully implemented, a stakeholder may not be satisfied, for instance, because the project funding bodies have not established a good working relationship with the customer. Hence, the second dimension should be taken into account. Stakeholders in an innovative project could be the project manager (university scientist), the customer, the organisation that carries out the innovative project, project team members, the funding body and anyone else affected by the process or outcome. An important measurement of the impact on the stakeholders dimension is the degree of satisfaction (e.g. Liu & Walker, 1998; Lynn & Reilly, 2000). The third dimension is associated with the achievement of the purpose and value of the project. The achievement of the objectives addresses the direct impact of the project on any stakeholder; for instance, often university scientists undertaking innovative projects have the intention of increasing their personal worth, e.g. through SCI papers and promotion. Measuring to what degree the project has achieved its objective, is also considered by many researchers to be important (e.g. Baccarini, 1999). The benefit to the investors, e.g. industrial collaborators and funding bodies, has a direct impact on whether the project is considered as good or bad in performance terms.

Some other variables are related to those associated with financial performance i.e. opportunity window, and market impact; indeed, these have been used to measure new product development projects in high-tech sectors (Cooper & Kleinschmidt, 1987; Dvir & Shenhar, 1992). Kerssens-van Drongelen and Cook (1997) argued that R&D projects should retain the balance between the following four perspectives: financial, international business, customer, and innovation and learning perspectives. The financial perspective is concerned with the project's contribution to profit; the internal business stance is concerned with efficiency and timelines; the customer perspective is related to quality of outcomes; the innovation and learning perspective is concerned with innovativeness of project members (Kaplan & Norton, 1996).

Although numerous dimensions have been employed in selecting performance measurement for innovative projects, the literature (e.g. Chiesa & Frattini, 2007) has suggested that it is possible to group the most commonly used in into four dimensions as presented in Table 2.5.

Table 2.5: Dimensions of Performance Measurement for Innovative Projects

Dimensions of performance measurement
Effectiveness
Efficiency
Contribution to value
Time

(Source: Chiesa, V. & Frattini, F. 2007. Exploring the differences in performance measurement between research and development: evidence from a multiple case study. R&D Management, 37(4): 238-301. P. 285)

Whilst the literature has provided a considerable number of performance measurements for innovative projects, these have mostly been derived from the industrial viewpoint. Therefore, the four dimensions listed in Table 2.5 are considered as guidelines, to explore whether university scientists would follow them in evaluating the performance of the innovative projects in which they are involved. Based on this, the development of integration of the elements of the initial framework for this study has been completed (Figure 2.8).

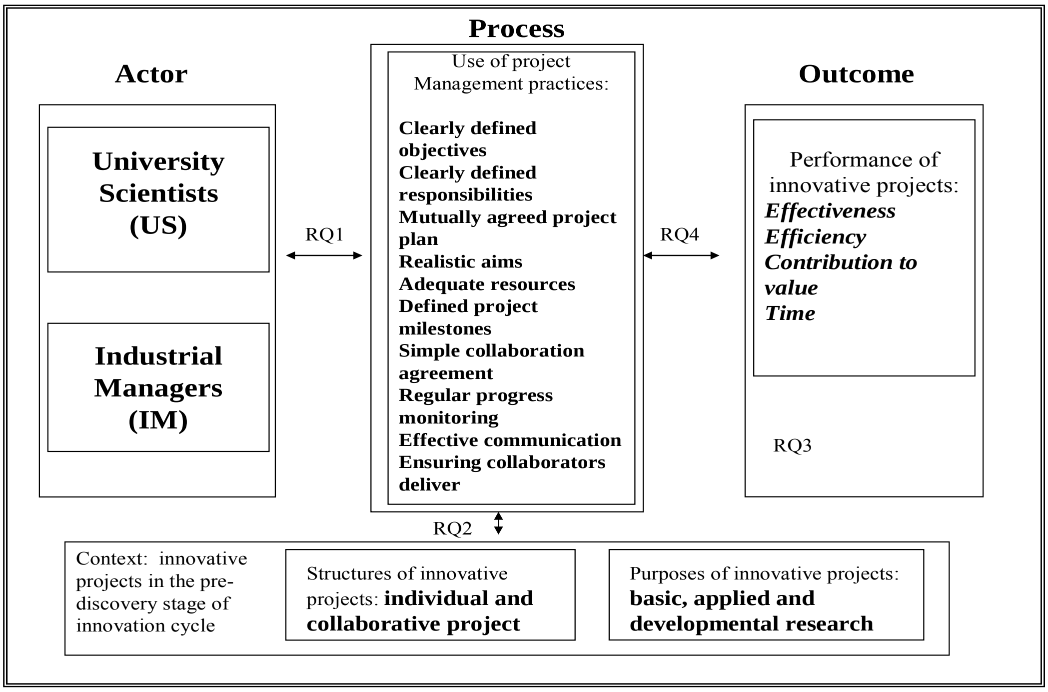

Figure 2.8: The Initial Framework Incorporating the Elements in all Constructs

In sum, it would appear that scope, time and cost measures are too simplistic to define project failure and success. A more comprehensive set of criteria for measuring needs to reflect different interests; scope, cost and time targets may be important for the project funding bodies, but not the university scientists. The dimensions of selection of performance measurements to be explored have been presented in Table 2.5. Thus, the rest of research questions of this study are formulated:

- RQ 3: how do university scientists (Actor) measure the performance of innovative projects (Outcome)?
- RQ 4: what impacts does the use of PM practices (Process) have on the performance of innovative projects (Outcome)?

2.5. Chapter Summary

This chapter has presented a literature review. The purpose of this was to build up the conceptual framework for this study from the initial one, and to explain the research questions, shown in Chapter One. The structure and purpose of innovative projects have been integrated into the context of this study, as they may influence the management of innovative projects. It has also been identified that university scientists in different environments may employ different management approaches to manage individual and collaborative projects. The PM practices to be employed in exploring how university scientists manage innovative projects have been presented. Finally, the four performance dimensions to be used to explore university scientists' actions during innovative projects have been shown as well.

Chapter Three: Research Methods

This chapter demonstrates the research methodology employed to address the research questions identified in Chapter Two. To begin with, Section 3.1 presents the issues regarding the research methods by outlining the research paradigm that has provided the philosophical basis of for the choice of research strategy and methods. In section 3.2, the two phases of research approach are introduced; the exploratory research phase followed by the explanatory phase. The exploratory stage aimed to clarify the understanding of the constructs of the conceptual framework mentioned in the previous chapters, particularly regarding the influence of the use of project management (PM) practices on the performance of innovative projects, and the explanatory research phase to test this understanding on a wider population of university scientists. Section 3.3 includes discussion of the chosen methods and the selection of semi-structured interviews as the research technique in the exploratory research phase. In section 3.4, concerning the explanatory research phase, the suitability of a survey method for the explanatory research phase is discussed. In addition, the research technique is considered. Section 3.5 describes the sampling for this study. Section 3.6 shows data analysis employed in both the exploratory and explanatory research phases, to uncovered patterns and to confirm them. Finally, section 3.7 summarises the discussions related to the research methods for this study.

3.1. Research Paradigm

A research paradigm can be seen as a basic set of beliefs that guide human actions (Denzin & Lincoln, 2000). Applying this to social research, a research paradigm guides how social researchers discover valid and reliable information from the social world. It contains four concepts: axiology, epistemology, ontology and methodology (Denzin & Lincoln, 2000). Axiology is concerned with the role of values in inquiry; epistemology is associated with the relationship of the knower to the known; ontology is concerned with the nature of reality; methodology is related to the best means for gathering knowledge about the world (Denzin & Lincoln, 2000; Easterby-Smith, Thorpe, & Lowe, 2002). These concepts are summarised in Table 3.1 below.

Table 3.1: Summary of the Concepts of Formation of the Research Paradigm

Concept	Description
Axiology	The role of values in inquiry
Epistemology	The relationship of the knower to the known
Ontology	The nature of reality
Methodology	The best means for gathering knowledge about the world
Method	Individual techniques for data collection and analysis

(Sources: adapted from Denzin, N. K. & Lincoln, Y. S. 2000. Handbook of Qualitative Research (2nd ed.) Thousand Oaks, CA: SAGE; Easterby-Smith, M., Thorpe, R. & Lowe, A. 2002 Management Research: An Introduction (2nd Ed.) London: SAGE Publications Ltd.)

3.1.1. Positivism and Social Constructionism

The discussions related to the research paradigm begin with two contrasting traditional philosophical positions, positivism and social constructionism. The key idea of positivism is that "the social world exists externally, and that its properties should be measured through objective methods" (Easterby-Smith et al., 2002, p.28). This statement illustrates the fact that the reality of positivist research is external and objective. This is the ontological assumption of positivism (Easterby-Smith et al., 2002; Wass & Wells, 1994). Positivist researchers should stand at a value-free and external position when they carry out social research (Bryman, 2001; Wass & Wells, 1994). This is because the epistemological assumption of a positivist is that "knowledge is only of significance if it is based on observations of this external reality" (Easterby-Smith et al., 2002, p.28). Moreover, positive research follows a reductive approach to measure the concepts being studied by quantitative data. Then, such measurements can demonstrate the truth or falsity of the hypotheses formulated. Consequently, such a position is more likely to test theories than to build them (Bryman, 2001; Easterby-Smith et al., 2002)

Social constructionism stems from the ontological assumption that "reality is not objective and exterior, but is socially constructed and given meaning by people" (Easterby-Smith et al., 2002, p.29). Epistemologically, the social reality within such a paradigm is determined by actors rather than by objective and external factors. Therefore, when social scientists tackle inquiry from this stance, they should appreciate "the different constructions and meanings that people place upon their experience" (Easterby-Smith et al., 2002, p.30). This indicates that within social constructivist research, the researchers are part of what is being studied and the interpretation of the observations is based on the 'consciousness' of the actors (Bryman, 2001; Easterby-Smith et al., 2002). Social constructivist research requires an inductive approach to understand what the actors are thinking and feeling, by qualitative inquiry to explain their actions (Easterby-Smith et al., 2002). Table 3.2 below shows the contrasting implications of these two positions.

Table 3.2: Contrasting Implications of Positivism and Social Constructionism

	Positivism	Social Constructionism
The observer	Must be independent	Is part of what is being observed
Human interests	Should be irrelevant	Are the main drivers of science
Explanations	Must demonstrate causality	Aim to increase general understanding of the situation
Research progress through	Hypotheses and deductions	Gathering rich data from which ideas are induced
Concepts	Need to be operationalized so that they can be measured	Should incorporate stakeholder perspectives
Units of analysis	Should be reduced to simplest terms	May include the complexity of the 'whole' situation
Generalizations through	Statistical probability	Theoretical abstraction
Sampling requires	Large numbers selected randomly	Small numbers of cases chosen for specific reasons

(Source: Easterby-Smith, M., Thorpe, R. & Lowe, A. 2002 Management Research: An Introduction (2nd Ed.) London: SAGE Publications Ltd. p. 30)

3.1.2. Mixed Methods and Paradigm

The methods and techniques of researchers tend to be guided by their philosophical position (Easterby-Smith et al., 2002). For instance, positivist research is usually conducted by deductive logic and quantitative data; social constructionist research, on the other hand, is usually undertaken by an inductive approach and qualitative information. Although these two positions have been recognized as comprehensive stereotypes for social science research, in practice the rigid boundary between these two has been increasingly blurred (Easterby-Smith et al., 2002). This is because any research method guided by the two extreme philosophical positions is increasingly insufficient for research regarding the 'real-world' (Robson, 2002) and 'management' (Easterby-Smith et al., 2002). Moreover, the two extreme paradigms may not be capable of dealing with a complex contemporary environment that demands a more flexible approach (Robson, 2002). Many researchers, especially in the management field, adopt a pragmatic view by deliberately combining the methods drawn from the above two traditional propositions (Bryman, 2001; Easterby-Smith et al., 2002).

It has been revealed that a paradigm guides a research project through research methodology, methods and techniques. Hence, the following discusses the paradigm guiding the mixed approach employed to social sciences. Pragmatism is a paradigm that stands in the position between positivism and social constructionism (Tashakkori & Teddlie, 1998), and that seeks to make a conscious compromise between a realist (positivist) and an idealist (social constructionist) understanding of social actions (Easterby-Smith et al., 2002; Wass & Wells, 1994). Consequently, such a paradigm appears to be able to integrate a realist explanation with a degree of subjective interpretation, and recognizes the "partial independence of the external world from subjective comprehension" (Wass & Wells, 1994, p. 17) in explaining human actions in the real world. The epistemological perspective of this paradigm is 'critical realism' (Wass & Wells, 1994), which does not rely solely on either inductive or deductive logic nor solely an qualitative or quantitative data. Such kinds of research may contain elements of both extreme positions (e.g. Easterby-Smith et al., 2002; Tashakkori & Teddlie, 1998; Wass & Wells, 1994). The comparison, in terms of the paradigmatic treatment of axiology, ontology, epistemology and methodology, between critical realism and other paradigms is presented in Table 3.3.

Table 3.3: Comparisons between Key Social Research Paradigms

Paradigms	Positivism	Postpositivism	Pragmatism	Social Constructionism
Methods	Quantitative	Primarily quantitative	Quantitative Qualitative	Qualitative
Logic	Deductive	Primarily deductive	Deductive and inductive	Inductive
Epistemology	Objective point of view Knower and known are the dualism	Modified dualism Findings probably objectively true	Both objective and subjective points of view	Subjective point of view Knower and known are inseparable
Axiology	Inquiry is value free	Inquiry involves values but they may be controlled	Values play a large role in interpreting results	Inquiry is value bound
Ontology	Naïve	Critical or transcendental realism	Accept external reality Choose explanations that best produce desired outcomes	Relativism
Causal linkage	Real causes temporally precedent to or simultaneous with effects	There are some lawful reasonably stable relationships among social phenomena. These may be known imperfectly. Causes are identifiable in a probabilistic sense that changes over time.	There may be causal relationships, but we will never be able to pin them down.	All entities simultaneously shaping each other. It is impossible to distinguish causes from effects.

(Source: Tashakkori, A. & Teddlie, C. 1998. Mixed Methodology: Combining Qualitative and Quantitative Approaches. London: SAGE Publications., p. 23)

3.1.3. Research Paradigm and Strategy

The choice of research paradigm should connect to the questions to be studied (Easterby-Smith et al., 2002). The purpose of this study is firstly to gain more understanding about the research questions posed in Chapter One, and, secondly, is to refute or support the conclusions emerging from the exploratory research, which can explain the concepts related to the research questions obtained from the university scientists' perspective in more detail. This indicates the need to combine both qualitative and quantitative approaches in the study. Such an approach refers to the theoretical perspective that social research is usually concerned with seeking a greater understanding of social phenomena, which explain human actions in response to external stimuli (Wass & Wells, 1994).

3.1.4. Ontology and Epistemology

This section illustrates the ontology and epistemology inherent in the theoretical perspective, with the purpose of describing whether the findings of this study are subject to falsification or verification.

Inherent in the theoretical perspective of pragmatism is the “multi-level” ontology of realism (Tashakkori & Teddlie, 1998). This ontology includes two basic questions: which knowledge is acceptable for this study? (Bryman, 2001) and “What is the nature of the knowable?” or “What is the nature of reality?” (Manunta, 2000, p. 20). As discussed, reality is determined by not only purely objective information, but also a certain degree of subjectivity influenced by the university scientists’ perception. Hence, as can be seen in Figure 3.1, the findings of this study regarding the research questions may not actually reflect the reality (real domain) or actual reality (actual domain), but may reflect the empirical reality (empirical domain) which may predominately, but not totally, exist only in the minds of the university scientists. Therefore, despite the ideal of objectivity as an assumption of the pragmatic epistemology (Manunta, 2000), this study can only consider findings as “probably true” and avoid any arrogance in viewing the findings in this study as “true” (Guba, 1994, p. 109). Justified true beliefs (Manunta, 2000) are generated, which are considered to be tendencies subject to falsification (Partington, 2000). In addition, Bhaskar (1975) argues that “roughly the theory advanced here is that statements of laws are tendency statements. Tendencies may be possessed unexercised, exercised unrealised, and realised unperceived by men; they may also be transformed” (p. 18).

As a consequence, in the context of this study, the patterns that emerge are seen as “imperfectly apprehendable” (Guba, 1994, p. 110). Thus, the findings are not absolute or verified laws, but probably tendencies, that is, they are neither unique nor generally applicable to every context in the real world. That is to say that the patterns that emerge from this work may be modified or altered as a result of other researchers implementing a similar study in a different context, at a different time or with different respondents. However, unless there is a methodological error, this does not indicate that the theories or patterns generated by this study are not valuable. On the contrary, this indicates that the failure to replicate the results in another research context does not conclusively falsify theories or patterns generated (Robson, 2002).

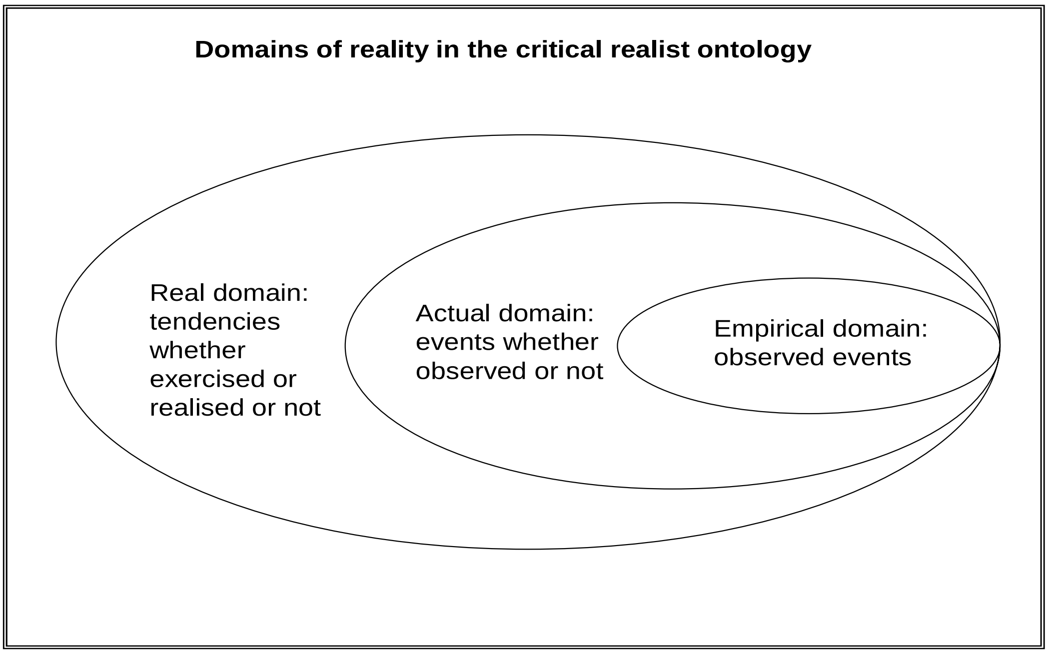

Figure 3.1: Critical Realist Ontology

(Source: Partington, D. 2000. Building grounded theories of management action. British Journal of Management, 11(2): 91-102, p. 98)

3.2. Research Design

This section shows the rationale behind the selection of a two-stage research procedure to address the research questions formulated in Chapter One. The focus of the unit of analysis of this study, and its operational measurements for assessing project performance, and for measuring the level of employment of PM practices are discussed.

3.2.1. Two-Stage Approach

The whole procedure of this study is divided into two phases – exploratory research and explanatory research. The former has the purpose of increasing the understanding of the research problem at the outset of the study, and the latter is to confirm the understanding at the end (Miles & Huberman, 1994). The exploratory research phase is for clarifying “your understanding of a problem” (Saunders, Lewis, & Thornhill, 2000, p. 78). It involves the purpose of discovery (Robson, 2002). As the research questions in this study are little understood from the university scientists’ point of view, especially in the project management and innovation management literature, the rationale for the exploratory research phase, at the outset, is that such an approach attempts “to find out what is happening, particularly in little-understood situations, to seek new insight, to ask questions, to assess phenomena in a new light, to generate ideas and hypotheses for further research" (Robson, 2002, pp. 270-271). At the end of the exploratory stage, there should be a better understanding of the patterns of the employment of PM practices and the performance of innovative projects being undertaken by university scientists. In addition, what contextual factors influence the patterns that emerge may be identified through the process of conducting the exploratory stage. Such an approach is often deployed in research to understand the areas which are under researched (Robson, 2002). For instance, some studies (e.g. Barnes et al., 2006; Khilji et al., 2006; Terziovski & Morgan, 2006) employed such an approach to identify factors regarding the success of UICs or innovations in the biotechnology industry, and to propose some 'best practice models' for the management of them.

In contrast to exploratory research, explanatory research aims to explain a situation or a problem (Robson, 2002), i.e. investigating the relationship between the identified and explored variables (Saunders et al., 2000). Moreover, explanatory research has the purpose of improving the understanding of concepts obtained from the exploratory research (Bryman, 2001). Therefore, the explanatory research of this study investigates any patterns that emerge during the exploratory research and also any newly emerging pattern that remains undiscovered in the first phase. That is to say, after obtaining a better understanding of the patterns in several cases, an informative but tentative conceptual framework is developed. For instance, in the exploratory research phase, it is suggested that two contextual factors, i.e. the purpose and structure of the innovative projects, that could influence the level of use of PM practices, and the patterns regarding how these two factors influence the level of the employment emerge. These patterns are revisited in the explanatory research phase for a better understanding, regarding how they influence the level of usage of PM practices. This is because the identification of the patterns in the first phase is based on the interview statements made by twelve university scientists (see Chapter Four) resulting in the limitations regarding their generalisation and predictive powers. Thus, it is the intention of this study to obtain evidence about these patterns from a wider population of university scientists, within the research context, with the purpose of reinforcing these generalisation and predictive power.

3.2.2. Unit of Analysis and Operationalisation of Measurements

This study sets out to investigate whether university scientists employ PM practices in managing innovative projects and what impacts such management has on project performance. This confirms that the unit of analysis in this work is at the project level.

As discussed in the literature review (see Section 2.3.3), the projects in this study can be assessed in four performance dimensions, i.e. effectiveness, efficiency, contribution to value and time. Nevertheless, these dimensions cannot be operatively measured unless one or more of their agreed components are appropriately selected (Ojanen & Vuola, 2006; Pappas & Remer, 1985; Sandstrom & Toivanen, 2002). Chiesa and Frattini (2007a) further stated that, in general, there are three concepts, regarding the operationalising of the measurements for assessing the performance of innovative projects. They are: qualitative subjective, quantitative objective, and quantitative subjective. Although these concepts are usually associated with performance measurements, in this study they are also used in the operationalisation of measurements for the level of employment of PM practices. This is because these are concepts that allow for operative measurements.

The qualitative subjective concept is employed in addressing research questions in the exploratory phase, because responses are not expressed numerically, but through the personal judgement of the evaluator. For example, in the interviews, the researcher asked interviewees to evaluate the success of the projects being undertaken by them through the questions (e.g. "Do you think the projects are a success?"). After the respondents answered the question, a follow up question was asked (e.g. "Why did you evaluate the project as a success/failure?").

Quantitative objective measurements are numeric metrics obtained from the application of a definite algorithm that brings to the same evaluation independently from the person responsible for the measurement (e.g. percentage of projects concluded on time, numbers of publication) (Chiesa et al., 2007). This concept is applied to operationalise some of the measurements in the survey. For instance, for one of the performance criteria, i.e. Numbers of SCI papers published, the operative measurements are "Please indicate how many SCI papers have been published or accepted during the period of 2002-2004".

On the other hand, quantitative subjective measurements are numeric metrics based on the personal judgement of respondents, whose subjective evaluation however, is translated into a numeric score through alternative techniques, e.g. a 5-point Likert scale (e.g. Collier, 1977; Gee, 1972; Whelan, 1976). Measurements regarding this concept are employed in the levels of employment of PM practices by the university scientists and the levels of the achievement of project performance, in terms of the criteria identified in the exploratory phase, as will be presented in Chapter Four. For example, in the questionnaire, respondents were asked to indicate "to what extent did the projects achieve project objectives within the proposed time schedule” and to what extent they agreed with the statement “I never change the project objectives during the project life cycle”, on the 5-point Likert scale.

For all of the questions asked in the exploratory and explanatory research phases, please see Appendices A and B, respectively.

3.3. Phase 1: the Exploratory Research

This section presents the research methods and techniques employed for the exploratory phase of the study. The purpose is to make sense of patterns associated with the influence of the application of PM practices by university scientists on the performance of innovative projects. Some significant studies have been conducted about this topic from the industrial point of view (e.g. Bart, 1993; Bonner et al., 2002; Omta & de Leeuw, 1997) and how industrial scientists behave (e.g. Miller, 1986; Sapienza, 2005); however, research on this from university scientists’ point of view is scarce. The existing literature and theories identified in the literature review fail to sufficiently inform this research in terms of appropriate enquiry. Therefore, the exploratory research has the purpose of generating patterns, which are based on the reality of the university scientists, to be tested in the explanatory research. This step prevents patterns being solely generated from the literature and intuition (Turner, 1981), with the consequence that they may have no relevance to what is actually happening in the innovative projects being conducted by university scientists.

3.3.1. Research Methods

As stated, the purpose of this stage is to explore how the actor in the frame of this study behaves, and then to generate provisional theories. The usual approach is to inductively derive such theories from the study findings. The researchers adopting such an approach are most likely to begin by collecting data within the research boundary, and then, to analyse it and generate theory (Backman & Kyngäs, 1999). In the exploratory phase, the labels of concepts which emerge are rather broadly defined at the beginning. With the gradual gathering of additional data, the concepts are changed and adjusted repeatedly, until these precisely capture all the appropriate categorised data. This is so as provide a valid and reliable, but provisional, pattern to be tested in the explanatory phase. Therefore, in this study two main methods were adopted for the exploratory phase. One of these included a comparative procedure or as previously described a process of reflexivity; the other method was the adoption of a theoretical sample rather than a representative sampling (see Section 3.5) (Hammersley, 1996).

By applying these two methods, the understanding of the research questions, in the research context of project management, was framed and then reframed, when the data gained from the university scientists and industrial people was analysed. The procedure for this was iterative. For instance, when a pattern emerged indicating that the specific employment of a PM practice by a university scientist has had a specific effect on the performance of an innovative project this pattern was either rephrased or confirmed by comparing it with the previous cases investigated. Thus, such an iterative process of proposing and checking of patterns or of interpretation and theorising, suggested by Bryman (2001), increases the level of understanding of this study arrives at the appropriate understanding of the relevant issue and facilitates the answering of the research questions.

Nevertheless, a significant problem – anecdotalism (Bryman, 2001) – may have arisen through the use of such an exploratory approach. This argument is that the exploratory research phase of this study focused on the qualitative analysis of subjective data, leading to the risk that it was just interesting stories about what happened, of unknown truth and utility (Miles & Huberman, 1994). However, the analysis in this study not only provided a descriptive account of cases but also included a stream of conclusion drawing and verification. By exploring the influence of the use of the PM practices on innovative projects in more than one case, the ability to compare cases represents a "powerful conceptual mechanism" (Stake, 2000, p. 242), leading to the evaluation of similarities and differences between individual cases or groups of cases (Eisenhardt, 1989; Yin, 2003). One strategy for searching for patterns suggested by Eisenhardt (1989) is to select categories, then to categorise each case and to look for within group similarities and inter-group differences. In this study, the comparison between established categories included, for instance, success of a project versus failure.

As a result, the exploratory research of this study has included a certain amount of data reduction which in turn has facilitated the formulation of a provisional theory open to further testing in the explanatory research. Bryman (2001) argued that "Because of the tendency towards unstructured, open-ended approach to data collection, qualitative research is often very helpful as a source of hypotheses or hunches that can be subsequently tested using a quantitative research strategy" (p. 449).

3.3.2. Research Techniques

As mentioned, the purpose of the exploratory phase was to understand the social reality of university scientists, how they have experienced the employment of PM practices and the influence of this usage on the performance of innovative projects. Thus, the research technique employed should firstly allow the researcher to obtain a richer and more detailed view of the social reality of multiple cases and to gain a more comprehensive understanding into what is relevant, from the university scientists' point of view. Secondly, the techniques can be employed to identify a range of different categories of the usage PM practices by university scientists, and the level of influence of their application on project performance assessed. The numbers of cases needed for this study were determined by its conceptual needs (Eisenhardt, 1989; Yin, 2003). In this respect, Keegan and Turner (2002), for example, explored the relevance of traditional innovation ideas to project-based firms by conducting twenty-two in-depth interviews, so that they could gain an insight into how senior managers perceived the application of those traditional innovation ideas in their context. Therefore, bearing in mind the purpose of the exploratory research, and the selection of techniques by other researchers, such as Keegan and Turner (2002), the technique of interview chosen for this study was seen to be the most suitable to explore the research problem and questions.

Interviews

Interviews are one of the most widely used methods of data gathering in social research and have been described as 'conversations with purpose'. They can discover specific factors or be more broadly and deeply concerned with human actions and beliefs (Robson, 2002). In addition to in-depth interviews, the research literature generally (e.g. Easterby-Smith et al., 2002; Saunders et al., 2000) distinguishes between two basic types of interviews: unstructured interview and semi-structured interview. Other studies have further differentiated between standardised and non-standardised interviews, although their definitions vary slightly (e.g. Patton, 1980; Saunders et al., 2000). Unstructured and semi-structured interviews are more likely to be associated with qualitative research, with small sample size and usually with an agenda of topics to be dealt with (Fontana & Fery, 2000; Saunders et al., 2000); whereas, the structured interview is more likely to be concerned with quantitative research with standardised questions, and with large sample sizes (Bryman, 2001). Bryman (2001) however, argued that a structured interview with standardised questions and a predetermined sequence may impose the researchers' view about managerial perceptions on the interviewee, leaving little space for the respondents own perspective. In addition, semi-structured interviews can seek both clarification and elaboration on the answer given, and then record qualitative information about the topic (May, 2001). Hence, for the purpose of exploring the research questions, a semi-structured interview approach was initially considered as most appropriate for this study.

The employment of semi-structured interviews enabled the gathering of rich and detailed data, for this study, about the social reality of university scientists, regarding their perceptions about the use of PM practices, the effectiveness of such use and project outcomes. This technique allowed for an insight into what the interviewees considered to be relevant. It provided the flexibility to adapt the questions to the specific social reality of university scientists in ‘real time’ (i.e. during the interview), that is, to the specific perceptions that they had, for instance, about the employment of PM practices, the effectiveness of their usage and the project performance of innovative projects.

As can be seen in Appendix A, the semi-structured interview design included key questions related to the background of the projects, the PM practices, perceived effectiveness of the use of PM practices and the outcomes of the innovative project. Some key questions to university scientists were asked as a starting point for discussion. These questions were open-ended to allow the interviewees to answer whatever and however they wanted. As a result, they could express their reality, and were able to provide valuable information, such as why and how they perceived the application of PM practices as effective. This assisted in the understanding of a pattern in a specific case and this pattern could then be compared with other cases. In addition, face-to-face interviews were carried out, as this type of interviewing process could observe non-verbal data, such as laughing, which may be helpful to interpret the meaning of the verbal data gathered from the interviews (Fontana & Fery, 2000). Face-to-face interviewing also allows interviewers to immediately follow up interviewees’ responses, which makes the information gathered more detailed (Fontana & Fery, 2000; Robson, 2002).

In the initial stage, pilot interviews were implemented to refine the main interview questions, which Robson (2002) has described as a complex social interaction. At the end of pilot interview, the respondents gave feedback. It was soon realised that the interview approach was flawed and had to be changed. The questions asked in the pilot interviews were too closed and not flexible enough. In fact, some questions were hypothetical and almost impossible for the interviewees to answer. The lessons learned through the pilot interviews were important as they enabled a re-think about the whole approach to the main interviews. This led to a more suitable interview technique, because the researcher had confidence to be more flexible to responses and thus the sessions were more successfully investigative. However, the actual data obtained through the pilot interviews was limited, because no holistic view was gained. Therefore, the data was excluded from the data analysis.

All of interviews were recorded, with the permission of interviewees, because note-taking can interrupt the interactive nature of the flow of the discussion (Patton, 1980), and may distract the interviewees (Bryman, 2001). All of the interviews were fully transcribed and the transcripts were checked for accuracy. Although time consuming, the advantages of recording are considerable: (1) it allows re-examination and a more thorough examination of the data, by the researcher, than is possible during the interview. Other researchers may access the recorded and documented data to examine the interviewees' bias. They may also use the data in the light of new ideas. In addition, as the interviews were conducted in Mandarin, translation of some of the important Mandarin statements into English was implemented after analysis. Owing to the constraints of time and manpower, not all of the interview statements were translated; in fact, only the valuable fragments of them were. All of the translated statements were reviewed by the interviewees, and there were discussions and amendments, if the interviewees thought the translation did not really reflect their opintions.

3.4. Phase 2: the Explanatory Research

This section presents how the researcher conducted the explanatory phase. The purpose was to examine whether the findings obtained in the phase one would apply to a wider population of university scientists, but still within the frame of this study. The rationale of employing the research methods and techniques are discussed in the following sections.

3.4.1. Research Methods

The purpose of the explanatory phase was to aim to test the patterns of the use of PM practices, the influence of the use on the performance of innovative projects and the project outcome within the 'real-life' context of those projects being undertaken by university scientists. However, the exploratory research and partial confirmation of the concepts through conceptual (or, theoretical) saturation (Strauss & Corbin, 1990), was based on a relatively small numbers of cases, owing to time and cost constraints. Although the conceptions and patterns gained from the exploratory phase could be seen as satisfactory, the confirmatory power of the results is relatively low (Strauss & Corbin, 1990). Thus, in order to generalise the findings from the exploratory research to all other university scientists in the research context of this study, a survey method, allowing for an increase in the degree of external validity (Bryman, 2001) (see Section 3.7), was employed.

3.4.2. Research Techniques

After the exploratory research, the researcher had a better understanding of what and how the use of PM practices by university scientists influenced the performance of the innovative projects. This understanding was based on patterns that emerged through the analysis of the data from the semi-structured interviews. The purpose of the explanatory research was to provide further evidence for these patterns and to test the patterns developed through the exploratory research on a wider population of university scientists. In research on innovative projects (e.g. NPD), the use of questionnaires to test provisional explanations (hypotheses) appears to be quite common. For instance, Dvir and Lechler (2004) used a questionnaire in order to understand whether the changes of project goal influenced project outcome (success or failure). Moreover, Omta and de Leeuw (1997) employed a questionnaire aiming to interpret the impact of control processes from top management on the uncertainty of R&D projects, and ultimately on the project outcome.

Questionnaire

The questionnaire technique is widely used in social sciences, evidenced by the fact that nearly everyone has experience of being surveyed (Bryman, 2001; Robson, 2002). Moreover, the technique provides a way of quantitatively linking theoretical categories or concepts with empirical research (Robson, 2002). This technique is dependent on a highly structured approach to data gathering. Data is gathered from a sample of people, from which it is possible to make predictions about how a larger sample of people would respond (Bryman, 2001; Robson, 2002). This prediction relies on the theory that the differences of opinion expressed are 'true' differences (May, 2001). These differences, may confirm patterns or relationships which emerged from the exploratory research, through statistical analysis. This means that the search for patterns or relationships focuses on the characteristics of a population rather than an individual (Bryman, 2001). Moreover, the researcher needs to have an understanding of the notions of causality and the meanings of the measurements associated with the questionnaires: the questionnaire data often presents causality as an explanation of human behaviour (Robson, 2002).

Table 3.4: Comparison of Approaches to Survey Data Collection

Aspect of survey	Self-completion questionnaire	Face-to-face interview	Telephone interview
Resource of factors			
Cost	Low	High	Low / medium
Length of data collection period	Long	Medium / long	Short
Distribution of sample	May be wide	Must be clustered	May be wide
Questionnaire issues			
Length of questionnaire	Short	May be long	Medium
Complexity of questionnaire	Must be simple	May be complex	May be complex
Complexity of questions	Simple to moderate	May be complex	Short and simple
Control of question order	Poor	Very good	Very good
Use of open-end questions	Poor	Good	Fair
Use of visual aids	Good	Very good	Not usually possible
Use of personal / family records	Very good	Good	Fair
Rapport	Fair	Very good	Good
Sensitive topics	Good	Fair	Fair / good
Data-quality issues			
Sampling frame bias	Usually low	Low	Low (with RDD[a])
Response rate	Difficult to get high	Medium / very high	Medium / high
Response bias	Medium	Low	Low
Control of response situation	Poor	Good	Fair
Quality of recorded response	Poor	Good	Fair

a: RDD stands for Random Digit Dialling

(Source: Czaja, R. & Blai, J. 1996. Designing Surveys: A Guide to Decisions and Procedures. Pine Forge: Thousand Oaks, p. 32)

Questionnaires (or self-completion questionnaires), which the respondents fill in for themselves, are particularly efficient in terms of research time and resources, as they are relatively cheap to administer and produce quick results (Czaja & Blai, 1996). As can be seen in Table 3.4 above, in comparison to the research techniques of face-to-face interviews and telephone interviews, a self-completion questionnaire has two distinct advantages that are considered important in this study, i.e. costs and distribution of sample. However, questionnaires are subject to a number of disadvantages, such as ‘does not allow for probing or clarification’ (Czaja & Blai, 1996). However, this researcher selected this type of questionnaire as the advantages mentioned earlier closely fitted the needs, in terms of the purpose of the explanatory research, and the resources that were available for this study.

A self-completion questionnaire (in this study, a self-completion web based questionnaire) is substantially cheaper to administer in comparison to other techniques, such as interviews (Fontana & Fery, 2000). In this work it was employed for the purpose of confirming or refuting patterns developed from the exploratory research using wider boundaries than was possible through interviews. It may have been more convenient for the respondents, because first, the set of questions was standardised and simple to answer and second, it was not necessary for the interviewer to present himself in front of the interviewees. However, the absence of an interviewer to explain a question which is not understood may result in the interviewees answering it wrongly or deciding not to respond. Moreover, checking the answers can be difficult and time-consuming. These are two major problems that may occur with this approach (see Table 3.4).

In order to tackle these potential problems, the first stage of surveying the university scientists included a pilot survey. The purpose of this was to practise the technique of using a self-completion web based questionnaire. The use of a pilot questionnaire may reveal technical problems, as well as offering the opportunity to test the measuring instruments and whether people accept the procedure of a web-based survey (Bryman, 2001).

Technical problems were not encountered during the trial. Afterwards some of those who had completed the questionnaire were contacted by the researcher by telephone, enquiring whether the questionnaire was clearly structured and whether there had been any difficulty in understanding the questions and response options. In addition, in order to increase the accuracy of the questionnaire, the respondents were asked how they interpreted some of the response options.

3.5. Sampling

3.5.1. The Exploratory Research

The population, from which the sample was drawn in the exploratory and the explanatory phases for this study, was university scientists in the biotechnology related departments, e.g. Life Sciences and Medicine, of universities in Taiwan. Regarding the exploratory research, Miles and Huberman (1994) argued that qualitative researchers tend to choose their sample purposively, rather than randomly. Whereas the chance of a case being selected is equal in probability sampling, non-probability sampling is more likely to be beneficial “to learn much from a non-typical case than a little from a typical case” (Stake, 2000, p. 243), and includes a subjective judgement (Saunders et al., 2000).

Therefore, non-probability sampling was emphasised during the exploratory phase for this study. In addition to the benefits mentioned previously, there is one other reason that motivated the emphasis of the exploratory research for this study. According to Yin (2003), four to ten cases are usually recommended for investigation; however, such figures are of an arbitrary nature and do not represent an absolute guideline for a researcher (Goulding, 1998). Thus, the sample size in the exploratory phase is determined by ‘conceptual saturation’ and this occurs when during an interview no new concept emerges to those that have been brough up in the previous interviews (Strauss & Corbin, 1990). This is the boundary of sampling for the interview. That is to say, the sample size in the exploratory phase was determined by conceptual (or, theoretical) saturation and this allows for a ‘more comprehensive’ insight into the research questions. Therefore, the numbers of interviewees were determined by the context and needs of this study. An overview of the background information of the projects that were qualitatively investigated is exhibited in Table 4.1 in the exploratory chapter (Chapter Four).

3.5.2. The Explanatory Research

Regarding the explanatory phase, the sample of respondents for the survey was determined randomly using a cluster sample. Cluster sampling involves the division of the whole population, in this study, the whole population of university scientists in the research context, into units with similar characteristics (Robson, 2002). Taking time and cost into account, cluster sampling becomes important (Bryman, 2001). This allowed the researcher to focus on one unit of university scientists in the biotechnology related departments at the universities in Taiwan and on the list of the PIs of innovative projects funded by the NSC (Taiwanese National Research Council). Instead of having to gain access to and to randomly select university scientists within the boundaries of this study from the entire Taiwanese population, thus saving time and costs during the data gathering stage.

Nevertheless, one of the disadvantages of a multi-cluster sample is sampling error (Bryman, 2001). Biases may arise due to the over-sampling of those who are within the research context, but not within the boundaries of the biotechnology industry, in accordance with the definition provided by the Taiwanese Ministry of Economic Affairs (MOEA) (NSC, 2003); for example, in the department of Life Sciences, the department needs some ecology lecturers or professors, who are not included within the boundaries of this study. As a result, it is likely that the numbers of university scientists undertaking developmental innovative projects are over-sampled. In addition, error may rise from the under-sampling of the university scientists whose research funding is usually from other funding bodies, e.g. private firms and foundations, rather than the NSC. As mentioned, the university scientists being selected for the survey samples were the PIs of the NSC, owing to the fact that its funding system covers most of university scientists who are involved in innovative projects. That is, those who were in the sample frame were at a certain educational level, such as PhD, and had experience in executing innovative projects. Consequently, the cluster sample chosen led to probable biases in the educational and experience levels. This may ultimately have limited the extent to which the findings of this study can be generalised.

The unit or cluster in the first pilot stage of the explanatory research included only two biotechnology related fields – immunology and plant sciences. The sample size of the pilot survey was fifteen and the population consisted of university scientists, who had at some time been PIs of the NSC, in the biotechnology related departments at universities in Taiwan. The pilot study led to revisions and a re-wording of the questionnaire. This revised questionnaire was used in the main stage of the survey. The sample size of the main survey was composed of approximately 800 university scientists in the sample frame defined for this study. The questionnaires were distributed via an email system with an invitation letter requesting responses, which was accessible through a web-link in the sent email. To increase the response rate, the university scientists were addressed as the PIs of NSC funded projects, from the university email address of the researcher. This gave greater credibility to the requests to complete the questionnaires, as they appeared to be of a formal nature. The background information of the respondents will be shown in Table 5.1 in the explanatory research chapter (Chapter Five).

3.6. Data analysis

3.6.1. The Exploratory Research

In the exploratory stage of this study, the numbers of interviews were increased until theoretical saturation was reached. According to Pandit (1996), theoretical saturation means “stable in the face of new data and rich in detail” (p. 4). Turner (1981) has suggested that saturation is achieved when a researcher is “fully aware of what is meant when any new phenomena encountered are classified into the category in question” (p. 235). However, the requirements about ‘theoretical saturation’ are unclear and do not accurately address the problem that “there is always something else to be found” (Marshell, 2002, p. 61). Accordingly, these arguments associated with theoretical saturation give researchers a very broad concept about when to stop gathering data.

In this study, the arguably ambiguous theoretical saturation was reached after having interviewed twelve university scientists. The new data obtained from the last interview could not add any new concept to the existing ones. That is, the concepts of the use of the PM practices and new interviews neither increased the range of their application nor did they considerably help the researcher to further understand each type of practice and its impact on innovative projects.

For the purpose of making sense of the qualitative data and generating patterns to be examined by the explanatory research, a template approach (Robson, 2002) was employed. The templates used were only those which were associated with the concepts already defined in the conceptual framework of this study. These templates served as the main categories (or codes) in the analysis process. The processing of qualitative data analysis has been recognised as a rather challenging task (Patton, 1980). Various authors have characterised the process of sorting and analysing qualitative materials as a 'spiral', with decreasing circles of iteration that leads to an account (Creswell, 1998), or as a 'ladder' where analysis involves climbing a series of stages to reach a conclusion (Carney, 1990), that is, theoretical saturation. Miles and Huberman (1994, p. 9) have provided a set of analytical processes, which appears to be generally accepted by most authors, including the following steps:

- Giving codes to the initial set of materials obtained from observations, interviews, documentary analysis, etc.;
- Adding comments, reflections, etc. (commonly referred to as "memos");
- Going through the material trying to identify similar phrases, patterns, themes, relationships, sequences, differences between sub-groups [sub-categories], etc.;
- Taking these patterns, themes, etc. out of the field to help focus the next wave of data collection;
- Gradually elaborating a small set of generations that cover the consistencies discerned in the data.

Therefore, the data analysis in this study followed these recommended process guidelines, with the main qualitative element being captured by the semi-structured interviews. That is to say that, this study focused on the spoken narrative and did not analyse non-vocal meanings, such as laughs, pauses or interruptions during the interview. Every interview was transcribed. Once transcribed, they were read holistically to get an 'idea' of the data without the imposition of a priori categories. Memos and notes were made in order to highlight any unexpected, unusual or key themes. Subsequent analysis benefited from the series of research questions developed in the previous chapters with each main category for analysis relating to the characteristics or variables being explored through these questions (Yin, 2003). Using these main categories, the transcripts were then coded and key quotations and sections of narrative were ordered (Strauss & Corbin, 1990). This process led to a series of further inter-related categories and sub-themes. That is to say, within these main categories, sub-categories and sub-themes emerged through the analysis of the data. Based on this process, key quotations, i.e. transcript segments, were labelled as sub-categories by incrementally including sub-themes under the main categories. However, not all of sub-categories and themes were examined by the explanatory research; indeed, those with limited supporting evidence were discarded, and those with related data were considered as one theme. Others associated with the research questions of this study were subsequently tested by the explanatory research of this study.

3.6.2. The Explanatory Research

In contrast to the exploratory phase, the analysis of the explanatory phase data included uni- and multivariate methods of analysis. The following steps were conducted:

- Descriptive statistics were provided, such as the mean score of each variable. In addition, an independent-sample *t* test was conducted to determine whether there was a significant difference between the variables, regarding the level of use of the PM practices in the different environments (George & Mallery, 2003; Hinton, Brownlow, McMurray, & Cozens, 2004; Kinnear & Gray, 2004), that is, this test was employed to determine whether contextual variables, i.e. structure and purpose of the innovative projects, influenced the level of use of the PM practices.

- The next step in the process was to calculate the Pearson correlation to measure whether there was a relationship between the variables, regarding the level of use of the PM practices and the level of achievement of the performance criteria of the innovative projects. A strong correlation would indicate that there was only a small amount of error and most of the points lay close to the regression line; a weak correlation would suggest that there was a lot of error and the points were more scattered (Hinton et al., 2004).

- Single and Multiple regressions were employed as a step in the analysis of the explanatory research to define the relationship and, in particular, to determine the level of causality between the variables related to the use of the PM practices and the performance of the innovative projects, being undertaken by the university scientists. Regressions are usually employed to investigate whether one variable reliably predicts other variables (George & Mallery, 2003; Hinton et al., 2004; Kinnear & Gray, 2004). The regressions were used for this study to examine whether the level of application of the PM practices, by university scientists, influenced the level of achievement of the performance of the innovative projects.

3.7. Quality in the Analysis

An important aspect of the quality process involves establishing and illustrating that the research study has been conducted in an open and honest fashion. The extent to which research may be reviewed as trustworthy and unbiased goes beyond intention and presentation (Robson, 2002). More fundamentally, the 'goodness' of any study and its findings are determined by the key questions that the researcher asks himself/herself during data collection and analysis. For example, as Miles and Huberman (1994, pp. 278-279) have suggested the following:

- Is the research design congruent with the questions being asked?
- Are the study methods and procedures described explicitly?
- Are areas of uncertainty identified?
- Are the findings congruent with, connected to the confirmatory of prior theory?

Therefore, the need for transparency and the ability to assess research findings has traditionally been achieved through considering work in relation to key criteria, embraced by the concepts of *validity* and *reliability*. In quantitative research (referring to the explanatory research of this study), from which these terms derive, quality concerns typically become divided, temporally, and applied to both the measurement and the findings of the data. In qualitative research (referring to the exploratory research of this study), where the process of measuring or collecting data and analysis often occur in tandem, quality concerns are more frequently considered together (Tashakkori & Teddlie, 1998). In addition, the nature of qualitative research means that quality issues have been extensively debated, as the applicability and relevance of criteria derived from quantitative traditions, have been questioned (Denzin & Lincoln, 2000). Whilst the debate remains ongoing, there is some broad agreement about how the criteria developed for qualitative methods may overlap with those from quantitative traditions (Easterby-Smith et al., 2002; Miles & Huberman, 1994). These relationships are depicted in Figure 3.2.

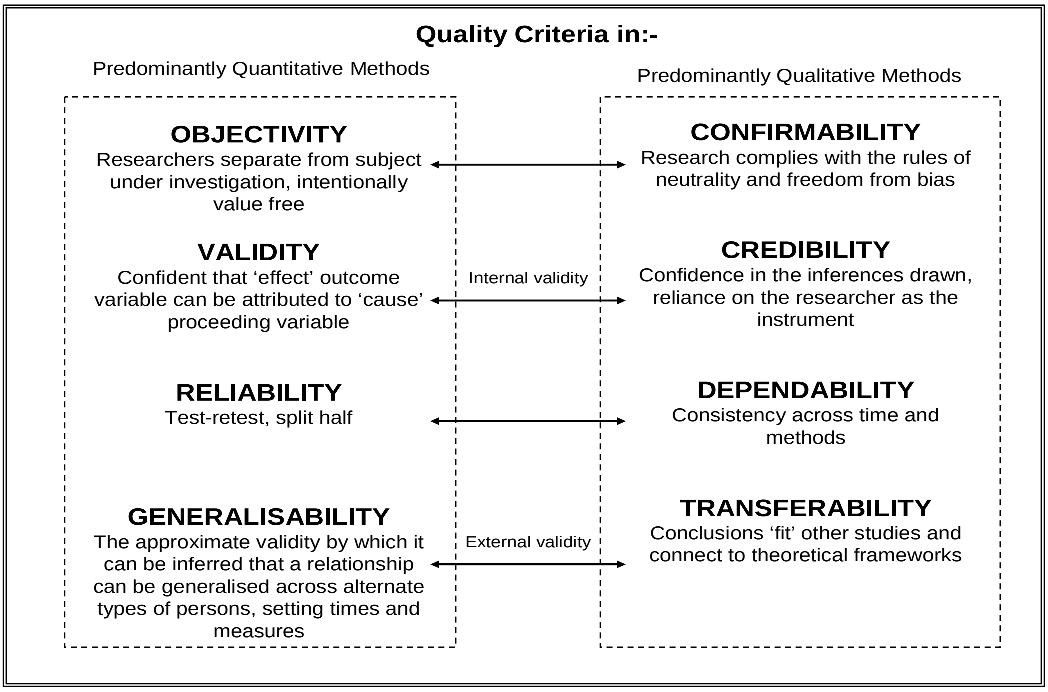

Figure 3.2: Quality Criteria in Research

(Sources: adapted from Easterby-Smith, M., Thorpe, R. & Lowe, A. 2002 Management Research: An Introduction (2nd Ed.) London: SAGE Publications Ltd., and Tashakkori, A. & Teddlie, C. 1998. Mixed Methodology: Combining Qualitative and Quantitative Approaches. London: SAGE Publications.)

Jankowicz (1991, p. 83) described a validity measure as being "accurate" and a reliability measure as being "precise". The test of internal validity relates to correctly establishing a causal relationship between variables; a relationship between variable X (e.g. the level of the use of PM practices) and Y (e.g. the performance of the innovative projects) might be also influenced by an another variable Z (e.g. contextual variable) (Yin, 2003). In order to increase the internal validity in this study, 'pattern match' (Easterby-Smith et al., 2002; Miles & Huberman, 1994; Yin, 2003) was applied. By this logic, in this study, patterns were constantly checked with the provisional patterns, to determine an unequivocal relationship between the variables. If a case fails to follow the pattern, it could lead to a revision of the patterns. If it shows a pattern which confirms the provisional pattern, further internal validity is generated through the explanatory research by applying statistical tests such as regressions.

External validity relates to the generalisation of the findings. External validity was generated in this study because of the choice of more than one case, i.e. innovative project. The similarity of cases within a group was likely to lead to a generalisation of findings during the exploratory research phase. Furthermore, the findings were tested on a wider population during the explanatory research phase. However, the acknowledgement of the dilemma of critical realism, described earlier, implies that on the one hand, the findings of this study cannot be used to anticipate all the conceivable applications of PM practices by university scientists in all settings. On the other hand, generalisation is not limited to a single case or to 'it just depends', as this study produced justified implications tendencies, about how the use of PM practices by university scientists influenced the innovative projects that they were involved in.

To ensure internal reliability, which deals with the issue of whether a different researcher is able to produce the same findings in a different context, potential investigators must be able to follow the same procedure as used for this study, in order to repeat it. Yin (2003) suggested there should be a case related protocol or a case related database. In this study, the process of applying research techniques and methods is documented. This documentation and this thesis include, for instance, an overview of the respondents including addresses, field procedures such as how the interview was implemented and case questions. The information documented is as follows: which university scientist was interviewed, how long the interview took, whether there were any interruptions or unanticipated events, which questions were changed and why and which questions were added or modified during the interview. External reliability is important in relation to using multiple-item scales as part of the survey questionnaire (Bryman, 2001). Concerning this, the Cronbach's alpha was calculated. As a rule of thumb, scales with a Cronbach's alpha over 0.8 are internally consistent (Bryman, 2001); however, this may decrease to 0.5 in exploratory research (Hair, Anderson, Tatham, & Black, 1998). However, the measurement employed to measure the variables were obtained from a single question and not an array, as is often the case.

3.8. Chapter Summary

In conclusion, two objectives for investigating the research questions have been identified. The first is the initial exploration of patterns and the second is to test these on a wider population. That is, to gain a better understanding of what and how the use of PM practices influences the performance of the innovative projects and to confirm the patterns for the whole population of university scientists in the sector under investigation. Consequently, for this study to achieve these two objectives within a pragmatist paradigm, including the use of a semi-structured interview technique, was seen as most beneficial in obtaining rich data to explore the research questions. Supplemented by a survey-based method composed of a web-based questionnaire sent by email, further confirmatory power on a wider population was gained, which led to increased external validity. Figure 3.3 below illustrates an overview of the methods and techniques employed in this study.

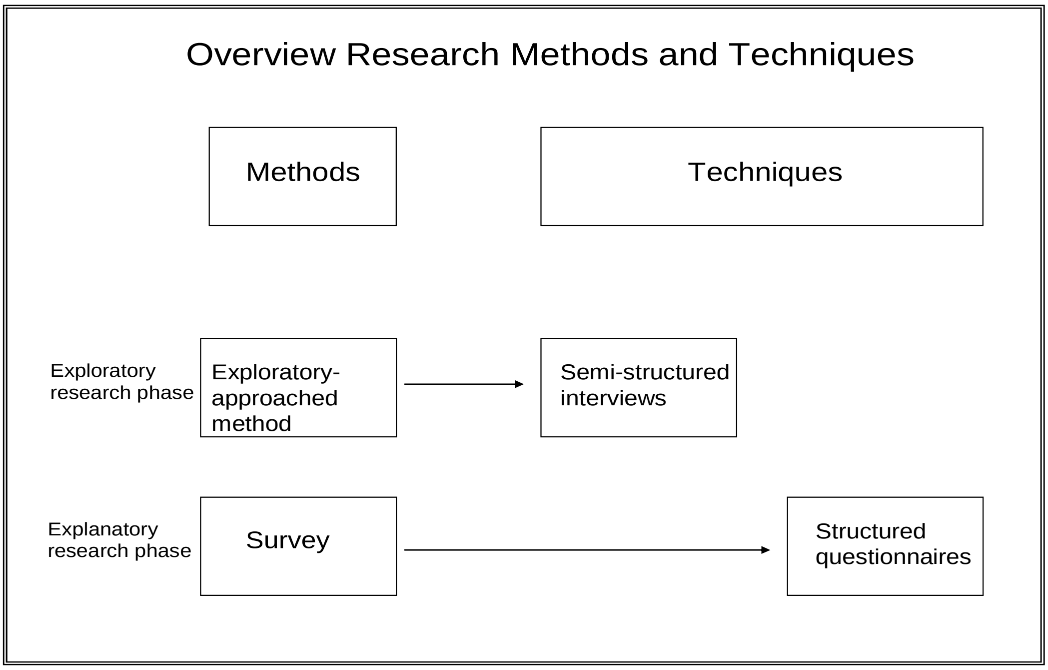

Figure 3.3: Overview of Research Methods and Techniques

The qualitative data gained through the interviews was analysed through a process of coding, until certain patterns about the influence of the use of PM practices on the performance of innovative projects emerged. These patterns were used to develop measurable scales for the explanatory research, and to carry out statistical analysis including independent-sample *t* tests and regressions, for the purpose of attaining validity for the relationships identified in the exploratory stage. Regarding the quality of the findings, the issues of validity, reliability and generalisability were taken into account for both the exploratory and explanatory research phases.

Chapter Four: Exploratory Research

This chapter describes the findings of the exploratory research of this study. In this phase interviews were conducted to gather rich data, in order to address the research questions formulated in Chapter One. The rationale behind the decision to use interviews was to obtain a more comprehensive understanding of whether university scientists employ PM practices when they are undertaking innovative projects, and ultimately, whether such usage influences the performance of such projects. This chapter is structured as follows. Section 4.1 describes the background information for the projects which were qualitatively investigated. Section 4.2 demonstrates the level of employment of PM practices by university scientists. In this section, the study also presents the findings regarding the differences in how university scientists employ the practices in individual (academic) projects, as compared with collaborative (commissioned) ones. Section 4.3 presents the influences of the contextual variables of the innovative projects that university scientists are involved in (i.e. the structure and purpose), regarding the level of employment of PM practices by them. Section 4.4 presents the findings regarding the project outcomes of the UICs investigated; in particular what criteria university scientists and industrial managers employed as the measurements of the performance of innovative projects, are revealed. Section 4.5 shows the findings related to the impact of the employment of PM practices on the performance of innovative projects. Section 4.6 revisits the research questions to be asked in the explanatory phase, because based on the findings of the exploratory phase, the elements (variables) of the constructs in the initial framework are refined and therefore there is a need to clarify the variables to be used in the explanatory stage. Thus, the research questions will be slightly changed to fit the variables identified. Finally, a chapter summary is provided. Figure 4.1 below illustrates the structure of this chapter.

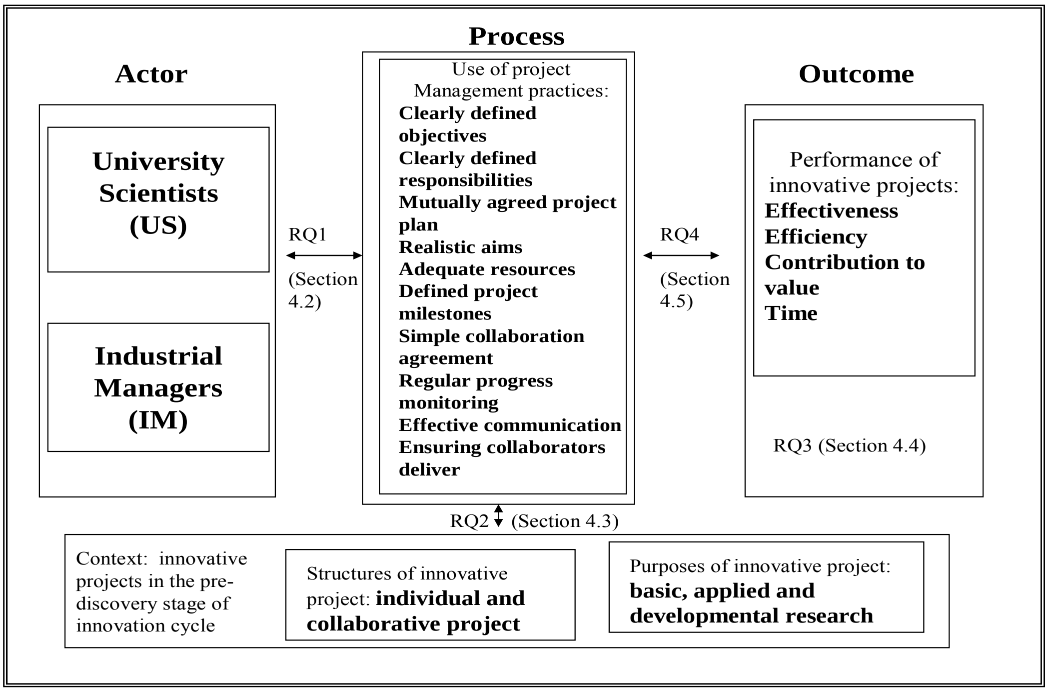

Figure 4.1: The Structure of Chapter Four

4.1. Background Information of the Projects Investigated

In this phase, twelve university scientists and nine industrial managers belonging to nine UICs were qualitatively investigated in early 2005, and the most of data gathered was associated with the projects that had been done before the year. Table 4.1 exhibits an overview of the background information of the projects investigated in the exploratory research. It shows that knowledge and technologies of modern biology, such as Molecular Biology, were being employed to carry out these projects, and they belonged to some categories of the biotechnology industry, such as agriculture, performance chemistry and biomedicine, as defined by the MOEA (NSC, 2003). Thus, all of the projects investigated were within the boundaries of the research context of this study.

Table 4.1: Summary of Profiles of the UICs Investigated

	Interviewees	Position in the collaboration	Position in his organisation	Codes of transcript	Size in terms of amounts of research funding[a, b]
Project A	Chen, PhD in Microbiology	PI	Professor, Southern Taiwan Univ. of S&T	Scientist A	1 Million[c] (M) / 3.2 M[d] [31.25%][e]
	Chen	Industry manager	President, YT bio-Farm	Manager A	
Project B	Chou, PhD in biochemistry	PI	Professor, Taiwan Univ.	Scientist B	2 M / 6.3 M [31.75%]
	Jeng, MSc in biology	Industry co-PI	R&D Vice President, YY biotech Co.	Manager B1	
	Yang, MSc in biology	Industry scientist	Deputy R&D manager, YY biotech Co.	Manager B2	
Project C	Hsia, PhD in biochemistry	PI	Associate Professor, Ping-Tung Univ. of S&T	Scientist C	1.1 M / 2.5 M [44.00%]
	Chen, PhD in biochemistry	Industry co-PI	President, All-tech, Taiwan branch	Manager C	
Project D	Cheng, PhD in Medical Engineering	PI	Professor, Yang-Ming Medical Univ.	Scientist D1	5.6 M (2.5 M)[f] / 4 M [62.50%]
	Hsu, PhD in Medical Engineering	Co-PI	Assistant Professor, Yang-Ming Medical Univ.	Scientist D2	5.6 M (1.5 M) / 2.2 M [68.18%]
	Lin, PhD in Physical Therapy	Co-PI	Associate Professor, Yang-Ming Medical Univ.	Scientist D3	5.6 M (1.6 M) / 2.7 M [59.26%]
	Liau, PhD in Medical Engineering	Industry co-PI	Manager, R&D Div., UO Corporation	Manager D	
Project E	Chou, MD, PhD in Medicine	PI	Professor, Medical School, Taiwan Univ.	Scientist E	3.5 M (2 M) / 4.2 M [47.62%]
Project F	Lin, PhD in Animal Sciences	PI	Professor, Ping-Tung Univ. of S&T	Scientist F	2.5 M / 5.2 M [48.08%]
	Cheng, MSc in Biochemistry	Industry scientist	R&D Scientist, K. Animal Vaccine Factory	Manager F	
Project G	Lai, PhD in Genetics	PI	Professor, Tsing-Hua Univ.	Scientist G1	3 M (2 M) / 6 M [33.33%]
	Chang, PhD in Embryology	Co-PI	Associate Professor, Chung-Sun Medical Univ.	Scientist G2	3 M (1 M) / 2.7 M [37.04%]
	Kerg, MSc in Medical Laboratory Sciences	Industry scientist	Vice Manager, KK Co. Ltd.	Manager G	
Project H	Lin, PhD in Molecular Biology	PI	Associate Professor, Chung-Sun Medical Univ.	Scientists H	1.2 M / 5 M [24.00%]
	Wu, BBA	Industry manager	President, ST biotech Co.	Manager H	
Project J	Wu, PhD in Food Sciences	PI	Professor, Ping-Tong Univ. S&T	Scientist J	1 M / 3.4 M [29.41%]
	Li, PhD in Pharmacology	Co-PI	Senior scientist, G&E Herbal Biotech	Manager J	

Table: 4.1 (continued)

	Size in terms of the numbers of collaborative research laboratories	Nature of research grant	Purpose of research	Duration	Field
Project A	2	Commissioned	Applied and developmental	Two years	Agriculture
Project B	2	Commissioned	Applied and developmental	Three years	Performance chemical
Project C	2	Commissioned	Applied and developmental	Two years	Animal health
Project D	4	Commissioned	Applied and developmental	Three years	Medical instruments
Project E	4	Commissioned	Basic and applied	Two years	Biomedicine
Project F	2	Commissioned	Applied and developmental	Two years	Veterinary
Project G	3	Commissioned	Basic and applied	Three years	Biomedicine
Project H	2	Commissioned	Applied and developmental	Three years	Biomedicine
Project J	2	Commissioned	Applied and developmental	Three years	Herb medicine

[a] 30% of the funding was from the firms involved in the UIC, and the rest of the funding was from Taiwanese government through the NSC.
[b] funding received in New Taiwan Dollar (NTD).
[c] indicating the level of research funding of the UIC.
[d] indicating the level of total research funding received in the PI's Lab, including academic grants and commissioned grants.
[e] the percentage of the research funding from the UIC compared with the total amounts of research funding received of PIs' laboratories.
[f] figures in parentheses indicate the portions of the research funding of the UIC allocated to co-PIs' laboratories.

In general, these UICs can be seen to be small projects in terms of the length of the collaborations, the numbers of collaborators involved, and the amounts of research funding received. Regarding the project duration, these collaborations were either for two years or three years; however, all of the UICs investigated, except for project J, have been granted continuous funding for further research. The numbers of collaborators involved is defined as the numbers of research laboratories involved in each UIC project. Regarding the UICs investigated, six of them were composed of two research laboratories; two of them included four collaborators; and one comprised of three research laboratories. In addition, all of the UICs investigated only included one industrial research laboratory.

According to a statistical report published in 2005 by the Taiwan National Science Council (NSC) (NSC, 2005), compared with science and technology in leading countries (e.g. the US, the UK and Japan), the amounts of research funding received by each of the UIC was rather small, from 1 million NTD[1] (New Taiwan Dollar) to 5.6 Million NTD. 70% of the research funding for each UIC was funded by the NSC, and the rest was paid by the firms involved with the project. That is to say, these UICs had to follow the application procedures and regulations established by the NSC during the life cycle. One of these is concerned with the project planning; applicants are asked to present a Gantt Chart-like table in the research proposal to provide guidelines for mid-term and final reviews, once the application has been approved.

With respect to the purpose of the projects investigated, this researcher has categorised the projects investigated as basic, applied and developmental research, based on the OECD's definition (OECD, 1980). However, none of these projects could be categorised as being for one of these purposes, alone. Indeed, according to the interview statements made by the interviewees, seven UICs were undertaking applied and developmental research projects, and the rest were carrying out basic and applied research projects. Regarding the resources of their research funding, the structures of all of these projects were seen as collaborative (commissioned) projects, as discussed in Chapter Two.

[1]Averaged annual Foreign Exchange Rate in 2004: ￡1 = 61.22 NTD. (Source: Central Bank of Taiwan, available at: http://www.cbc.gov.tw/economic/statistics/fx/fx-y.pdf)

4.2. Employment of Project Management Practices

This section presents the findings addressing the Research Question 1:

- RQ 1: to what extent do university scientists (Actor) use PM practices (Process) to manage innovative projects?

For this study, ten PM practices were chosen, as suggested by a 'best practice model' for managing UICs (Barnes et al., 2006). Table 4.2 below shows the summary of qualitative findings, concerning whether the university scientists interviewed employ the PM practices provided by the 'best practice model' (Barnes et al., 2006). The table presents the following findings: whether each of PM practice is employed by the university scientists, and to what level, i.e. for each PM practice the notation used is: applied (V), applied but as guideline (※) and not applied (X). In addition, the table presents the differences in the levels of implementation of PM practices between collaborative (commissioned) and individual (academic) projects, of the university scientists interviewed.

Table 4.2: Summary of the Levels of Employment of PM Practices Highlighted by University Scientists

Projects	outcome	PM Practices									
		Defined Project Objective	Clear Defined Responsibilities	Mutually Agreed Project Plan	Realistic Aims	Adequate Resources	Defined Project Milestones	Regular Progress Monitoring	Effective Communication	Ensuring Collaborators Deliver	Good Project Manager
A	Success	V[a], (※)[b]	X, (X)	V, (V)	V, (V)	X, (X)	X, (※)	X, (※)	V, (V)	V, (V)	X, (X)
C	Success	V, (※)	X, (X)	V, (V)	V, (V)	X, (X)	V, (※)	V, (V)	V, (V)	V, (V)	X, (X)
D	Success	V, (※)	X, (X)	V, (V)	V, (V)	X, (X)	V, (※)	V, (※)	V, (V)	V, (V)	X, (X)
E	Success	X, (※)	V, (X)	V, (V)	V, (V)	X, (X)	X, (※)	V, (V)	V, (V)	V, (V)	X, (X)
F	Success	V, (※)	X, (X)	V, (V)	V, (V)	X, (X)	V, (※)	V, (V)	V, (V)	V, (V)	X, (X)
J	Success	V, (※)	V, (X)	V, (V)	V, (V)	X, (X)	V, (※)	V, (V)	V, (V)	V, (V)	X, (X)
H	Failure	V, (※)	X, (X)	V, (V)	V, (V)	X, (X)	V, (※)	V, (V)	V, (V)	V, (V)	X, (X)
B	Ambiguous	X, (※)	X, (X)	V, (V)	V, (V)	X, (X)	X, (※)	V, (V)	V, (V)	V, (V)	X, (X)
G	Ambiguous	X, (※)	X, (X)	V, (V)	V, (V)	X, (X)	X, (※)	V, (※)	V, (V)	V, (V)	X, (X)

V = Applied; ※= Applied but as guideline; X = Not applied

[a] symbols shown indicate the degree of the application of the PM practices to the UIC (i.e. collaborative (commissioned) innovative projects) by the university scientists interviewed

[b] symbols shown in the brackets indicate the degree of the application of PM practices to individual (academic) projects by the university scientists interviewed

Overall, only three of the PM practices suggested by the model were selected for the explanatory phase. These three practices were: ‘Defined Project Objective’ (DPO), ‘Defined Project Milestone’ (DPM), and ‘Regular Progress Monitoring’ (RPM). The rationale behind this is explained in the following sections.

4.2.1. Practices Not Selected for the Explanatory Phase

As can be seen in Table 4.2, ‘good project manager’ and ‘adequate resources’ were not applied by any of university scientists interviewed. The absence of ‘good project manager’ responses is probably as a result of the university scientists’ mindsets, believing that the role of project manager was to keep projects on the original track, and to keep scientists away from non-scientific matters, e.g. administrative and financial efforts (e.g. Sapienza, 2005; Terziovski & Morgan, 2006). Therefore, the university scientists claimed they should not become a project manager (Chiesa, 2001); instead, they should be the leaders of scientific labour (e.g. providing vision, setting up scientific policies) (e.g. Cohen et al., 1999b; Sapienza, 2005; Terziovski & Morgan, 2006). For instance, the university scientist in project A, who had experience of working in the industrial sector, explained:

> *“At present, most university scientists in the biotechnological sector are not used to having managed R&D [innovative] projects or even recognising what management is about – i.e. making things happen according to a preconceived plan.” (Scientist A)*

Moreover, the university scientist in project F for example stated:

> *“R&D [innovative project] needs good leadership, rather than good manager. Unfortunately, there is an almost total failure to distinguish between management and leadership. The latter involves such characteristics as inventiveness, imagination, intellectual bravery and innovation. Management is more prosaic involving the capacity to make thing happen according to a preconceived plan, firmness, and courage in the face of a defiance and common sense. However, top management, e.g. policy makers, the research council, seem to encourage us to be mangers rather than leaders.” (Scientists F)*

In terms of ‘adequate resources’, none of interviewees claimed it was employed by them, as all of the university scientists interviewed pointed out that this was more likely to be the concern of the funding bodies or top management (e.g. Cohen et al., 1999b; de Leeuw, 1990), as will be presented later. For example, almost all of the interviewees from the universities stated that they had been granted follow-up research funding for further research, because the results of the project, being undertaken by them, had satisfied their collaborators and funding bodies. For instance, a university scientist in project G explained:

> *"… if a project does not have a good performance, for example, publishing SCI papers or achieving pre-stated objectives, it will not be continued at the next grant application. I think it is the best way to manage or monitor project progress from them. Therefore, such practice is more suitable to be applied by funding bodies, such as the NSC." (Scientist G1).*

As a consequence, these two practices – 'good project manager' and 'adequate resources' – were excluded from this study, that is, they would not be the variables that were employed to examine the relationship between the use of PM practices and the performance of innovative projects.

4.2.2. Practices Selected for the Explanatory Phase

Whilst all of the remaining PM practices were employed by the university scientists at different levels (see Table 4.2), not all of them were applied to the explanatory research for this study; indeed, only three of these PM practices – DPO (Defined Project Objective), DPM (Defined Project Milestones) and RPM (Regular Progress Monitoring) – were selected for the explanatory research. The rationale behind this selection is that: (1) all of these of three PM practices were applied to both collaborative (commissioned) and individual (academic) innovative projects; (2) there was a difference in the degree to which these practices were employed in collaborative and individual innovative projects; and (3) there were different levels of employment of the practices between in the projects investigated.

Most of university scientists interviewed suggested that some of the PM practices identified should be categorised into the same group. Interviewees suggested Realistic Aims, Defined Project Objective, Defined Project Milestones, Clear Defined Responsibilities and Mutually Agreed Project Plan should be integrated into a single category. This was because they thought that it was not possible to define project objectives without realistic aims, and the mutually agreed project plan was a final result of objectives, milestones and responsibilities being clearly defined. The university scientist in project A, for example, explained:

> *"A commonly agreed research proposal was set up. We saw this proposal as a contract between the lab [university scientist], the firm and the NSC [the major funding body of the project], and the guideline for executing the project. As a result, I had to propose a project objective that needed to be achieved, and to set up a serial of milestones that have to be met in order to reach the final objective. … yes, each partner's responsibilities were defined in the proposal, such as I had to achieve which milestones within a certain time-span, and then the firm and the NSC had to make certain amounts of payment to me. … Do you think this project will be granted funding without a realistic aim? So, from my point of view, I am not able to isolate these PM practices [realistic aims, defined project objectives, clearly defined responsibilities, defined project milestones and mutually agreed project plan], and I would suggest these practices should be seen as the same thing." (Scientist A)*

Moreover, the industrial managers' approaches supported this view. The industrial manager in project A was an example of one of those without a scientific background. He stated:

> *"…I was not involved in conducting the research tasks because, to be honest, I was not capable of doing so. I just told him [Scientist A] what I wanted and needed. Then, he started preparing a research proposal that could meet my requests. During the period of planning, we communicated quite often in order to ensure the project was really what I wanted and feasible." (Manager A)*

Furthermore, this view did not appear to be associated with whether the actors had received scientific education or not. For instance, the Manager C, holding a PhD degree in Biochemistry, claimed: "I had a lot of discussions with my partner [the university scientist in project C] in order to establish a reasonable and feasible project objective, milestones and the time-span needed to meet our [the firm] aim" (Manager C).

This suggests that DPO and DPM are most likely to be seen as parts of the same process when UICs are being undertaken. However, some studies have argued that DPO and DPM should not be treated as being the same, as their functions appear to be different when they are being employed to manage innovative projects (e.g. Brown & Eisenhardt, 1995; Dvir & Lechler, 2004; PMI, 2004; Shenhar et al., 2002). For instance, project objectives are more likely to be seen as long-term strategic objectives, and project milestones as short-term project goals, as will be discussed in the discussion chapter (Chapter Six).

Defined Project Objective

Before proceeding, what is worth noting here is that this researcher defined the level of the application of DPO as the degree of the changes in the DPO during the life cycle of innovative projects; in other words, the higher the level of the change in the DPO, the lower the level of employment of DPO. Table 4.3 below presents an overall view of the application of DPO to the UICs investigated, from the perspectives of both the university scientists and the industrial managers.

Table 4.3: The Employment of DPO in UICs

Projects	Outcome	Application of DPO	
		University scientist perspective	Industrial manger perspective
A	Success	"… I had to propose a project objective that needed to be achieved, as the NSC requested …" (Scientist A)	"… Then, he [scientist A] started preparing a research proposal that could meet my requests." (Manager A)
C	Success	"We did define the project objective, as the NSC and my collaborator requested." (Scientist C)	"…in order to establish a reasonable and feasible project objective, milestones and the time-span needed to meet our [the firm] aim" (Manager C)
D	Success	"I did apply both [project objectives and milestones] because I think they are important and other stakeholders requested them." (Scientist D1)	"… project objective is important to us [the firm], as it is related to our business plan" (Manager D)
E	Success	"I always define the project objective, as I think it helps me to keep on the right track. Also, the NSC ask me to do so" (Scientist E)	Data is not available
F	Success	"I emphasise quite a lot the importance of the definition of project objective because it is like a light tower guiding the direction of the project" (Scientist F)	"We [the firm] defined a project objective for this project, as we saw the objective as a milestone of our business plan." (Manager F)
J	Success	"I did define the project objective for this project, as we [university scientist and firm] saw the project as a contract for our collaboration." (Scientist J)	"The Project objective was required, as it was seen as the contract for the collaboration, and it is a part of our [the firm's] business plan." (Manager J)
H	Failure	"We [university scientist and the firm] defined a project objective, as it was helpful to keep to the direction of the project. However, we were too optimistic because we were not able to control the assess to experimental materials" (Scientist H)	"We [university scientist and the firm] defined the project objective for the project in order to keep to the direction of the project." (Manager H)
B	Ambiguous	"A project objective is needed to undertake any R&D [innovative] projects but the objective should not be very rigid over long term. …" (Scientist B)	"… defining the project objective is required, or we do not know how to set up our business plan" (Manager B)
G	Ambiguous	"Although this project was basic research, the project objective was needed; otherwise, a UI R&D collaborative projects may go to in another direction" (Scientist G1)	"… without defining a project objective, you may not be able to know which way you have to go when you are facing several different data." (Manager G)

Based on Tables 4.2 and 4.3, DPO was employed by all of projects investigated, but the levels of such usage varied. For example, some university scientists claimed that DPO was very important and helpful in maintaining the direction of the projects, even Scientist H, whose project failed, agreed with this, (e.g. Scientists F, G, and H), but others though it was not necessary to seriously to take DPO into account, i.e. seeing DPO as guidelines, (e.g. Scientists A and B). In addition, all the university scientists interviewed claimed that they also employed DPO in individual (academic) projects, but most of them viewed the DPO as a guideline when they were undertaking such projects. Therefore, this suggests that the level of employment of DPO by university scientists in collaborative projects (UICs) is higher than in individual projects. Table 4.4 presents the difference in the degree of employment of DPO between collaborative and individual projects, from the university scientists' point of view.

Table 4.4: Differences in the Level of Employment of DPO in Collaborative and Individual Projects

Project	Outcome	Application of DPO to…	
		Collaborative innovative projects	Individual innovative projects
A	Success	"… I had to propose a project objective that needed to be achieved as the NSC requested. …" (Scientist A)	"… for an academic project, project objectives is temporary, as research may change from time to time" (Scientist A)
C	Success	"We did the define project objective, as the NSC and my collaborator requested." (Scientist C)	"…when I undertake academic projects, I see the project objective as changeable." (Scientist C)
D	Success	"I did apply it because I think it is important and other stakeholders requested it." (Scientist D1)	"… However, I usually do not define a fixed one for an academic project, my research may lead me anywhere" (Scientist D)
E	Success	"I always define the project objective, as I think it helps me to keep on the right track. Also, the NSC ask me to do so" (Scientist E)	"…if you see the project objective is fixed when you are carrying out academic projects, you may not be able to enjoy research when you observe interesting results." (Scientist E)
F	Success	"I emphasise quite a lot the importance of the definition of project objective because it is like a light tower guiding the direction of the project" (Scientist F)	"…However, I see this [project objective] employed to an academic project as a guideline, that is, it is flexible." (Scientist F)
J	Success	"I did define the project objective for this project, as we [university scientist and firm] saw the project as a contract for our collaboration." (Scientist J)	"A project objective is required for academic projects but it may be altered by breakthrough knowledge or technologies." (Scientist J)
H	Failure	"We [university scientist and the firm] defined a project objective, as it was helpful to keep to the direction of the project. However, we were too optimistic because we were not able to control the assess to experimental materials" (Scientist H)	"… for an academic project, the results of experiments determine the objective." (Scientist H)
B	Ambiguous	"A project objective is needed to undertake any R&D [innovative] projects but the objective should not be very rigid" (Scientist B)	"… defining the project objective is important but you can not treat it as fixed when you are carrying out academic projects " (Scientist B)
G	Ambiguous	"Although this project was basic research, the project objective was needed; otherwise, a UI R&D collaborative projects may go to in another direction" (Scientist G1)	"…I do define a project objective when I start establishing an innovative project. However, objectives employed to academic research are much looser because the NSC does not care about this." (Scientist G1)

Comparing the right two columns in Table 4.4, it suggests that university scientists appear to maintain a higher degree of the use of DPO in collaborative projects. For example, Scientist E always employed DPO when he was carring out innovative projects; however, he suggested that the DPO should not be treated as unchangeable when it was employed in individual projects. He asserted: "…if you see the project objective is fixed when you are carrying out academic projects, you may not be able to enjoy the research when you observe interesting results" (Scientist E). Moreover, the higher level of the application of DPO in collaborative projects appears to be as a result of the requests made by other stakeholders, e.g. industrial collaborators and funding bodies. For instance, Scientist G1, undertaking a basic and applied UIC, stated that his lower level of employing DPO in individual (academic) projects, was a result of the lack of rigour in auditing by the NSC, i.e. funding bodies, (see Table 4.4).

The findings presented above, have shown that the process of employing DPO by university scientists could depend on the purpose and structure of projects. Regarding this process, a university scientist in project G explained it as follows:

> *"… setting up project objectives is always useful, otherwise one tends to splash about during research. … I do define a project objective when I start establishing an innovative project. However, objectives employed in academic research are much looser, that is, they are not fixed but changeable, because science can happen at anytime and anywhere. To clarify this, I should say that I will try to retain the project objectives during the project when I carry out UI R&D collaborative projects, but the project objectives tend to be more flexible when I undertake academic innovative projects. " (Scientist G1)*

This implies that university scientists could change the defined project objectives during the life cycle, and this is most likely when they are working on projects, which have higher degrees of uncertainty. In addition, industrial managers appear to recognise that such changes are inevitable, even though they tend to retain DPO as a constant during the project life cycle, in order to keep to their business plan. For example, the industrial managers in project J explained:

> *"… setting up a clear project objective for this project was very important to us [the firm], as the formulation of business strategies and plans were based on the project objective. In fact, we [the firm] see this as a milestone of the business plan. So, it would be better if the project objective was unchanged. However, this appears not to be possible, because is not easy to predict what outcomes will be produced from the project; actually, the objective was slightly modified. Nevertheless, this was acceptable, as we realised an R&D [innovative] project is highly uncertain." (Manager J)*

This indicates that although university scientists define project objectives at the beginning of the implementation of UICs, they could change those defined during the project life cycle. Also, it shows possible reasons explaining why university scientists employ DPO at lower levels during individual projects, compared with when they are involved in UICs.

In sum, this study suggests that university scientists appear to employ DPO considerably in managing innovative projects that they are involved in, and there is a higher level of the employment of DPO in collaborative projects as compared to individual projects. However, whether this argument could be applied to a wider population of university scientists will be statistically tested in the explanatory phase of this study.

Defined Project Milestones

The interviewees took the view that DPM was important for monitoring the progress of UICs, as shown previously, indicating that project milestones were associated with project efficiency. Table 4.5 displays an overall view of what university scientists and industrial managers thought of the employment of DPM when they were undertaking collaborative projects.

Table 4.5: The Employment of DPM in UICs

Projects	Outcome	Application of DPM	
		University scientist perspective	Industrial manger perspective
A	Success	"… Project milestones in this project are seen as a series of control points, by which we [university scientist and the firm] can check the progress of the projects. But they may be changed in terms of the change of environment, e.g. new technologies or markets." (Scientists A)	"Meetings were usually for progress reporting based on the check points [project milestones] defined at the beginning. But we did not see these points as a restriction to our [university scientist's and the firm's] project." (Manager A)
C	Success	"We did define project milestones, as the NSC and my collaborator requested. Also, I would like to emphasise that milestones are helpful to monitor project progress." (Scientist C)	"…in order to establish the reasonable and feasible project objective, milestones and time-span needed to meet our [the firm] aim" (Manager C)
D	Success	"I did apply both [project objectives and milestones] because I think they are important and other stakeholders requested them." (Scientists D1)	"… we [the firm] requested the setting up of a series of milestones, and we checked the progress by these milestones." (Manager D)
E	Success	"We [university scientist and the firm] defined milestones when we were preparing the research proposal. The NSC and research team can check the project progress." (Scientist E)	Data is not available
F	Success	"…, defining project milestones was not only for me and the NSC, but also for the firm because timing is one of the most critical factors associated with launching new product on the market." (Scientist F)	"We [university scientist and the firm] identified a set of project milestones as our progress control points for the project." (Manager F)
J	Success	"We [university scientist and firm] had lots of discussions in order to define the project objective and milestones. …" (Scientist J)	"Setting up milestones and monitoring project progress against these milestones was a very useful process." (Manager J)
H	Failure	"We [university scientist and the firm] defined a set of project milestones in order to check the progress although we did not use them at all." (Scientist H)	"We [university scientist and the firm] defined milestones for checking project progress …" (Manager H)
B	Ambiguous	"I would say that establishing milestones is likely to be a helpful process. Certainly, without milestones, the entire research progress may not be manageable …" (Scientist B)	"… Defining project milestones is helpful to check the project progress" (Manager B)
G	Ambiguous	"Project milestones help me to check project progress, but it is not necessary to seriously take milestones into account." (Scientist G1)	"… although we [university scientist and the firm] established a set of milestones for checking project progress, he [Scientist B] appear not to use these milestones seriously." (Manager G)

Based on Table 4.5, it can be seen that the employment of DPM by university scientists is highly associated with the process of monitoring project progress.

Furthermore, DPM has been seen as a useful tool for monitoring project progress. For instance, Scientist G1 explained: "I would say that establishing milestones is usually a helpful process [for UI R&D collaborations]. Certainly, without milestones, the entire research progress may not be manageable …" (Scientist G1). Moreover, from the industrial manager's viewpoint, such a desire was supported. For example, Manager J stated that: "Setting up milestones and monitoring project progress against these milestones was a very useful process" (Manager J).

Following this view, DPM should not be changed during the life cycle of innovative projects. However, this opinion appears not always to hold true, as has been shown in Table 4.2, the level of employment of DPM is lower than that of DPO. This indicates that, from the university scientists' point of view, the former is less likely to be treated as a constant, compared to the latter, during the project life cycle. In fact, most of the interview statements, abstracted and presented in Table 4.5, showed that the university scientists frequently redefined DPM during the project life cycle. For example, Scientist A viewed DPM as a set of points for checking project progress, and such points may be altered in order to catch up with changes in the environment, such as the changes in technologies and markets. He stated:

> *"…Project milestones in this project are seen as a series of control points, by which we [university scientist and the firm] can check the progress of the projects. But they may be changed in terms of the change of environment, e.g. new technologies or markets being developed." (Scientists A)*

Furthermore, in terms of the industrial managers' point of view on the employment of DPM, whilst they would have liked to keep DPM unchanged during the project life cycle, such a desire was less likely to become reality. For example, the industrial manager in project F stated: "… it would be better if these [project milestones] were unchanged. However, this seems not to be possible…" (Manager F). Moreover, the industrial manager in project A explained:

> *"Meetings were usually for progress reporting based on the check points [project milestones] defined at the beginning. But we did not see these points as a restriction to our [university scientist's and the firm's] project, because doing so may stop us recognising the real progress and results of the experiments, and thus failing to keep up with new technologies or markets." (Manager A)*

Similar to the use of DPO, the level of employment of DPM is likely to be attributed to the structure (i.e. collaborative vs. individual) of innovative projects. Table 4.6 below illustrates the difference between the level of employment of DPM in the collaborative and individual projects covered by this study.

Table 4.6: Differences in the Employment of DPM in Collaborative and Individual projects

Project	Outcome	Application of DPM to…	
		Collaborative innovative projects	Individual innovative projects
A	Success	"…Project milestones in this project are seen as a series of control points, by which we [university scientist and the firm] can check the progress of the projects. But they may be changed in terms of the change of environment, e.g. new technologies or markets." (Scientists A)	"… For an academic project, project milestones are seen as guidelines. The NSC [major funding bodies for academic research] does not care about whether my projects meet the milestones." (Scientist A)
C	Success	"We did define project milestones, as the NSC and my collaborator requested. Also, I would like to emphasise that milestones are helpful to monitor project progress." (Scientist C)	"… Regarding academic research, project milestones are guidelines to me. They help me to monitor students' progress." (Scientist C)
D	Success	"I did apply both [project objectives and milestones] because I think they are important and other stakeholders requested them." (Scientists D1)	"… However, I usually do not define fixed ones for an academic project, because my research may lead me anywhere" (Scientist D1)
E	Success	"We [university scientist and the firm] defined milestones when we were preparing the research proposal. The NSC and research team can check the project progress." (Scientist E)	"I usually make an allowance to identify the project milestones when I am carrying out the academic projects." (Scientist E)
F	Success	"…, defining project milestones was not only for me and the NSC, but also for the firm because timing is one of the most critical factors associated with launching new product on the market." (Scientist F)	"In terms of conducting academic projects, project milestones are reminders that remind me what I have not done and what I have to do." (Scientist F)
J	Success	"We [university scientist and firm] had lots of discussions in order to define the project objective and milestones. …" (Scientist J)	"Project milestones are helpful to monitor project progress but they are less likely to remain, as research is highly uncertain and the NSC does not care about this." (Scientist J)
H	Failure	"We [university scientist and the firm] defined a set of project milestones in order to check the progress although we did not use them at all." (Scientist H)	"… for academic projects, results of experiments may alter the project milestones defined previously." (Scientist H)
B	Ambiguous	"I would say that establishing milestones is likely to be a helpful process …" (Scientist B)	"…but, regarding academic projects, it [the project milestone] is more likely to be the way to find a 'better way' to do something ... " (Scientist B)
G	Ambiguous	"Project milestones help me to check project progress, but it is not necessary to seriously take milestones into account even when conducting commissioned projects." (Scientist G1)	"I agree we [university scientists] need project milestones to monitor progress, but these milestones may be re-defined according to the results of the experiments, particularly in undertaking academic innovative projects. It is more likely to be the way to find a 'better way' to do something ..." (Scientist G1)

Scientist G2 explained the following:

> *"I think academic projects should be free from having monitored project progress. However, in reality, academic projects should be monitored, for both scientific content and for economic accountability. The best way of doing this, in my opinion, is to have the science vetted by peers and the economic vetted by funding bodies. Unfortunately, not all university scientists are geniuses, so there needs to be some internal checks, for example, project milestones, on the scientific content … Therefore, project milestones can be seen as guideline to apply to academic projects." (Scientist G2)*

The statements above suggest that university scientists' attitude towards employing DPM is similar to that for DPO; however, the milestones are more frequently redefined during the project life cycle in accordance with the progress and results of the experiments. Hence, this researcher claims that the level of use of DPM in innovative projects is lower than the level of use of DPO.

Regular Progress Monitoring

The interviewees argued that some of the PM practices suggested by the 'best practice model', i.e. Regular Progress Monitoring (RPM), Effective Communication and Ensuring Collaborators Deliver, can be seen to be in the same category, and these practices can be represented by RPM. This interpretation is based on interview statements that RPM allows, firstly, "every team number to communicate and exchange ideas, resources, etc." (Scientist G1). This indicates that good levels of communications are needed in order to conduct RPM effectively. Secondly, the purpose of "monitoring project progress is to help any team number to make progress" (Scientist G1). This implies that one of the functions of undertaking RPM is "ensuring collaborators deliver" from the university scientists' point of view. Finally, RPM takes place through research meetings which function as a platform for, in addition to sharing ideas, information and resources, solving problems and addressing conflicts that have occurred between team members, in order to keep the project moving forward. For example, the industrial manager in project C described the following:

> *"I had lots of discussions with my university collaborator in order to set up a set of project objective and milestones … However; the final ones were usually a result of compromise after conflicts of opinion between us. … During the project, we monitored the project progress through regular group meeting; in addition, we [university scientists and the firm] often*

discussed through informal communications to solve problems that arose whilst an experiment was being conducted. We [university scientist and the firm] have very good channels to communicate with each other. However, I would like to make it clear that effective regular meetings are needed because meetings are not only for monitoring project progress, but also for sharing information and ideas, solving problems and accumulating knowledge." (Manager C)

Table 4.7 below presents an overall view of what university scientists and industrial managers thought of the employment of RPM when they were undertaking innovative projects.

Table 4.7: The Employment of RPM in UICs

Project	Outcome	Application of RPM	
		University scientist perspective	Industrial manger perspective
A	Success	"… We [university scientist and the firm] did set up regular meetings for the project, but these points were seen as reference points. In fact, we discussed the project with each other quite often through informal meetings …" (Scientist A)	"…, I usually left him [scientist A] alone unless he called for meeting. Meetings were usually for a progress report based on the check points defined at the beginning. But we did not see these points as a restriction to our [university scientist's and the firm's] project." (Manager A)
C	Success	"Regular lab or group meetings are helpful to get to know the real project progress, and to solve the problems that cause delays of progress. We [university scientist and the firm]" (Scientist C)	"…during the project, we monitored the project progress through the regular meeting. In addition, we [university scientists and the firm] often discussed through informal communications how to solving problems that arise whilst the experiment is being conducted " (Manager C)
D	Success	"We [university scientists and the firm] met regularly for progress report; in addition, we discussed the results and progress of the experiments from time to time to determine the next step when undertaking experiments or to solve problems delaying the project progress." (Scientists D1)	"… we [the firm] checked the progress by these milestones, and removed the problems delaying project progress" (Manager D)
E	Success	"I organised regular meeting to monitor the project progress and to solve problems." (Scientist E)	Data is not available
F	Success	"… Regular meetings are required for any project. Of course, I met my collaborators regularly for reporting project progress and keeping the project moving forward." (Scientist F)	"We [university scientist and the firm] met regularly, and I though it was helpful in making progress." (Manager F)
J	Success	"We [university scientist and firm] had lots of discussions in order to … monitor project progress …" (Scientist J)	"Having group meeting was a very useful process to monitor project progress and keep the project moving forward." (Manager J)
H	Failure	"We [university scientist and the firm] met regularly at the beginning, but did not do so after the half way through the project, because the function of the meetings, keeping the project moving, no longer existed." (Scientist H)	"We [university scientist and the firm] defined milestones for checking project progress …" (Manager H)
B	Ambiguous	"I checked project progress through group meetings ..." (Scientist B)	"…He [university scientist] monitored project progress and solved most of problems during the group meeting." (Manager B)
G	Ambiguous	"… lab or group meeting allows team members to communicate and exchange ideas, resources, etc. [in addition], monitoring project progress is to help team members to make progress" (Scientist G1)	"We had a bi-weekly meeting. We [all team members] presented the progress in the meetings. If any delays have happened, we would try to find out the reasons and suggest possible solutions. I think this was helpful to keep the project on course." (Manager G)

Based on Tables 4.2 and 4.7, it can be seen that the university scientists and industrial managers in projects A, D and G appear not to have evaluated RPM as an important practice; however, the interviewees in the other projects saw such practice as a critical tool for managing innovative projects. However, based on the interview statements, this does not mean that the university scientists applying RPM at a lower level consider this PM practice as unimportant. Nevertheless, they pointed out that, in addition to *regularly* monitoring project progress, there were informal communications to monitor project progress, from time to time. Thus, the importance of RPM was lessened by informal communications, i.e. '*irregular* project monitoring'.

For example, the scientist in project A stated: "…We [university scientist and the firm] did set up regular meetings for the project, but these points were seen as reference points. In fact, we discussed the project with each other quite often through informal meetings …" (Scientist A). Moreover, Scientist D1 stated: "We [university scientists and the firm] met regularly for progress reports; in addition, we discussed the results and progress of the experiments, from time to time to determine the next step when undertaking experiments or to solve problems delaying the project progress" (Scientists D1). In terms of the industrial managers' point of view, they held a similar position on the application of this PM practice. Manager A, for example, stated:

> *"…I usually left him [scientist A] alone unless he called for meeting. Meetings were usually for a progress report based on the check points defined at the beginning. But we did not see these points as a restriction to our [university scientist's and the firm's] project." (Manager A)*

Unlike the applications of DPO and DPM, most of the university scientists interviewed did not claim that there was a difference in the degree of employment of RPM in collaborative and individual innovative projects. However, the university scientists in projects D and G took the view that there is a difference because, as they stated, RPM is more likely to be applied to collaborative innovative projects, in order to ensure the particular objectives are met. Such projects usually involve other stakeholders, e.g. industrial collaborators and funding bodies, who are concerned about the progress of the projects, and thus there is increased importance placed on *regular* project monitoring.

A university scientist in project D explained:

> *"… in my opinion, if the project is a commissioned one, regularly monitoring project progress is good for managing the projects because I am not likely to be able to communicate with collaborators informally, when I need to discuss anything associated the project. However, in terms of internal project progress, I do not see these meetings as useful apart from them putting pressure on team members and keep them up to speed when it is applied to academic projects. On the other hand, we can discuss or have a chat about the project when it does not involve outsiders." (Scientist D1)*

In addition, a university scientist in project G stated:

> *"… If the final product is not for commercialisation, regularly monitoring project progress does not need to be audited nor the product verified. For example, academic basic research in biomedical research sets out to study the fundamental problems of life. The development of novel ideas is more important than other matters. In addition, such kinds of projects usually do not involve others. Thus, monitoring project progress undertaken in academia, without collaborators, is more likely to be a process for communication, exchanging ideas and accumulating knowledge. On the other hand, it is worth arranging regular meetings to monitor project progress when UI R&D collaborations [UICs] are being undertaken, as for collaborators regular meetings appear to be more convenient." (Scientist G1)*

In sum, section 4.2 presented the qualitative findings concerned with to what extent university scientists employ PM practices, in managing collaborative and individual innovative projects. Three PM practices, i.e. DPO, DPM and RPM, have been identified, and applied to manage innovative projects by the university scientists investigated. In addition, the level of application of RPM by the university scientists was the highest, being followed by, in descending order, the employment of DPO and DPM. Moreover, the structures (i.e. collaborative vs. individual) of innovative projects appear to influence the levels of usage of the PM practices highlighted by the university scientists. However, the degrees of the influence are different. The degree of this influence on the level of employment of RPM is the lowest. The levels of this influence on the other two PM practices – DPO and DPM are similar to one another. However, whether the arguments above could be applied to a wider population of university scientists will be statistically tested in the explanatory research stage. Furthermore, as has been pointed out the framework of the PM practices, illustrated in Chapter Two has had to be re-drawn to show the elements of the practices selected for analysis in the explanatory phase. This is illustrated in figure 4.2 below.

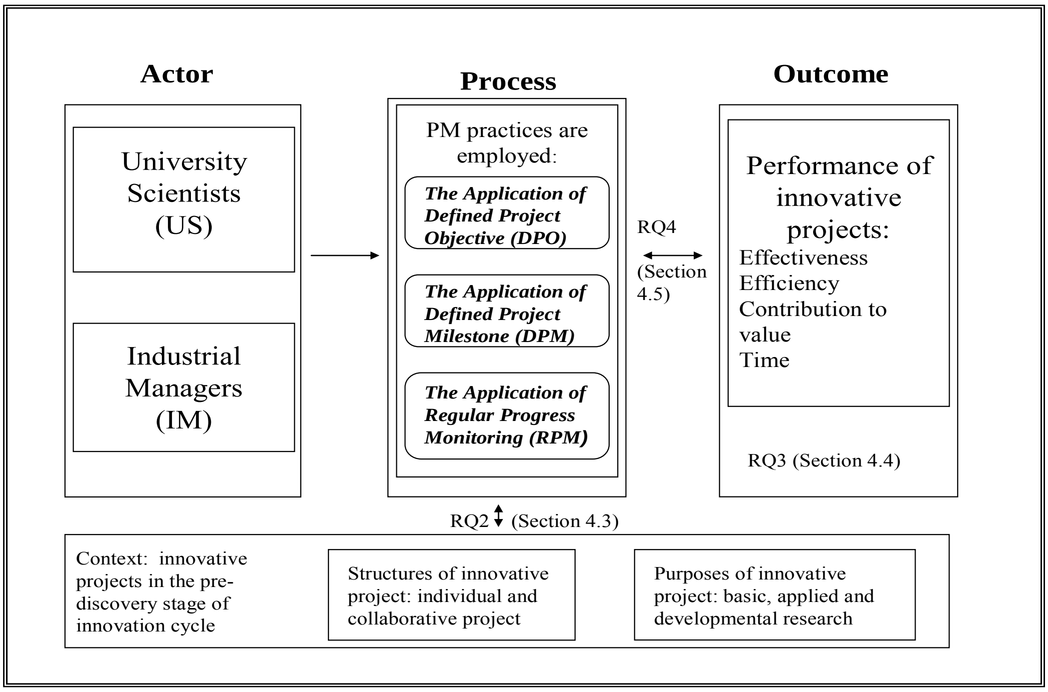

Figure 4.2: The Framework Incorporating Identified PM Practices

4.3. Influences of the Contextual Variables

As shown, the employment of PM practices by university scientists may be affected by the structure and purpose of the innovative project, and research question 2 was formulated as:

- RQ 2: how do the structure and purpose of innovative projects impact on the use of PM practices (Process) by university scientists (Actor)?

This section presents the qualitative findings addressing research question 2.

4.3.1. Structure – Collaborative vs. Individual

Although all of UICs investigated are characterised as collaborative innovative projects, based on the interview statements gathered from the university scientists, as will be presented later (Section 4.4), it has been proposed in this study that the structure of innovative projects could influence the level of the employment of PM practices. This because almost all of the university scientists interviewed mentioned that the ways of conducting collaborative (commissioned) projects differed from when they were undertaking individual (academic) ones, in terms of the degree of keeping defined project objectives and milestones as constants during the project life cycle, and the processes of conducting PM practices, e.g. the frequency of *regular* research meetings. In addition to the interview evidences will be presented in Table 4.8, here is another statement made by one of the university scientists interviewed, which reinforces this argument. Scientist C stated that:

> *"…the commissioned [collaborative] projects are mostly interested in benefiting business or the economy, whereas the academic [individual] projects are concerned with science. Therefore, this difference leads university scientists to use different ways to exercise R&D [innovative] projects. Based on my own experiences, I carefully considered whether results would meet the defined project objectives and the project progress when I was conducting commissioned projects. By comparison, I might change the research proposal as soon as a very interesting and attractive result comes out when I am conducting academic projects, as science is based on a 'trail-and-error' process, and progress may determine the project direction." (Scientist C)*

4.3.2. Purpose – Basic, Applied and Developmental Research

It can be seen in Tables 4.3, 4.5 and 4.7, the interviewees claimed that the level of the use of PM practices by university scientists during innovative projects, was likely to be influenced by the purposes of the projects, which had different levels of uncertainty. A university scientist in project G, for instance, stated: "I usually do not see project objectives and milestones as rigid because the nature of R&D [innovative] projects is highly uncertain" (Scientist G2), echoing the opinion of the industrial manager in project G: "… I would like to establish fixed ones in order to make my business plans more easily. But it does not seem to be possible, as I realise R&D [innovative] projects are highly uncertain" (Manager G).

Whilst innovative projects have been widely acknowledged as having high levels of uncertainty (Turner & Cochrane, 1993), the degree of uncertainty of such projects is likely to vary. Some literature (e.g. Omta & de Leeuw, 1997; Roussel et al., 1991; Turner & Cochrane, 1993) has suggested that the degree of uncertainty, in order, from highest to lowest is: basic, applied and developmental research. This is because of the following facts. Firstly, in basic research it is difficult to define the project objective and methods (referring to type 4 projects based on Turner and Cochrane's definition, as will be discussed later). Secondly, the project objective and the processes of applied research would have been identified in advance (referring to type 3 project). Finally, regarding developmental research projects, their projects objectives are well defined but the processes are not (referring type 2 project). In addition, Roussel and colleagues (1991) suggested that the innovative projects involving basic and applied research are more likely to be categorised as radical innovative projects, and those involving developmental research are more likely to be seen as incrementally innovative.

Comparing the projects with the different purposes may provide an indication of how this variable influences the level of the application of PM practices, by university scientists. For example, project G was defined as a basic and applied research project, and project C was categorised as an applied and developmental research project. Thus, the degree of uncertainty of the former should be higher than the latter. The level of use of PM practices does appear to be influenced by the purpose of innovative projects. Table 4.8 presents a comparison of the use of PM practices between projects categorised as being for different purposes. It can be seen that, the levels of use of DPO and DPM appear to be different, based on the statement by Scientist G 1 that although these two were important and applied, they were more likely to be used as guidelines during the project life cycle. However, Scientist C took these into account more seriously. However, the level of use of RPM would appear to be the same regardless of the project purpose. In addition, having examined the evidence presented in Table 4.8, the reason for the differences in usage of RPM appears to be contrary to what the above literature has proposed, i.e. the level of degree of uncertainty. It is more likely to be associated with the outside stakeholders, as Scientist C, for example, stated that "the NSC and my collaborator requested it". This will be considered in the discussion chapter, and the selection of these three PM practices will be presented later in this chapter.

Table 4.8: Comparison of the Levels of Employment of PM Practices Identified

Project	Purpose	Employment of DPO	Employment of DPM	Employment of RPM
G	Basic and applied research	"Although this project was basic research, the project objective was needed; otherwise, a UI R&D collaborative projects may go off course" (Scientist G1)	"Project milestones help me to check project progress, but it is not necessary to seriously take milestones into account." (Scientist G1)	"… lab or group meeting allows every team numbers to communicate and exchange ideas, resources, etc. [in addition], monitoring project progress is to help any team numbers to make progress" (Scientist G1)
C	Applied and developmental research	"We did define a project objective, as the NSC and my collaborator requested." (Scientist C)	"We did define project milestones, as the NSC and my collaborator requested. Also, I would like to emphasise that milestones are helpful to monitor project progress" (Scientist C)	"Regular lab or group meeting is helpful to know the real project progress, and to solve the problems that cause the delay of progress." (Scientist C)

In sum, the qualitative findings show that the structure and purpose of innovative projects appear to influence the level of use of PM practices by university scientists. However, in order to seek a more reliable generalisation of these findings, they will be statistically tested in the second phase, i.e. explanatory research. Figure 4.3 shows the qualitative findings.

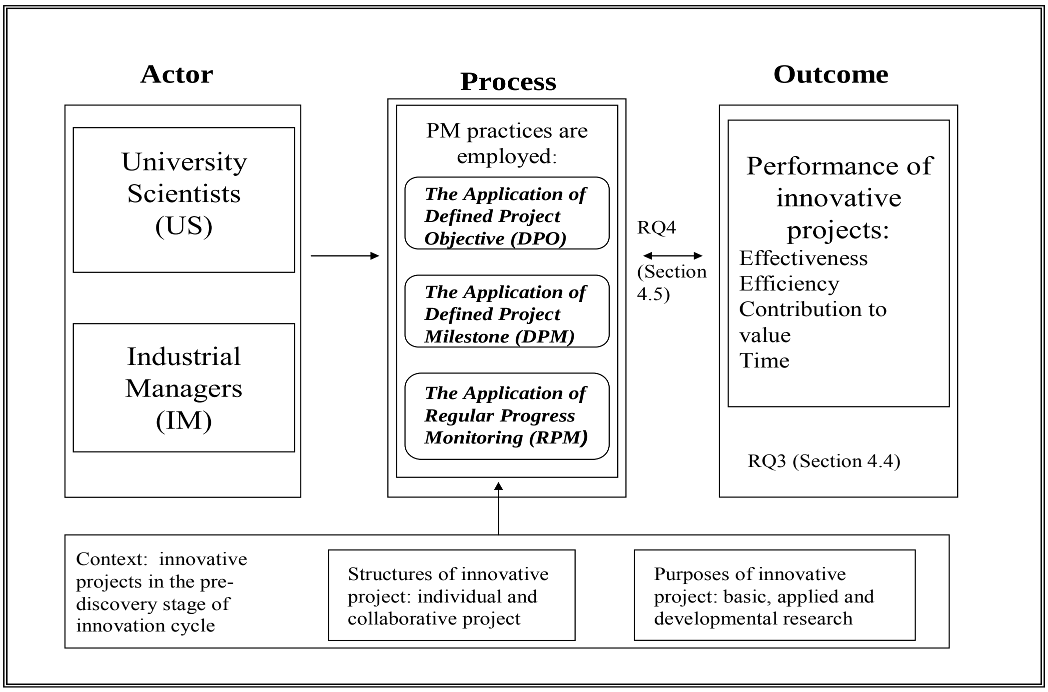

Figure 4.3: Findings Addressing Research Question 2

4.4 Outcome (Performance of Innovative Projects)

This section shows how the university scientists evaluated the performance of innovative projects, aiming to address the Research Question 3 formulated in Chapter One:

- RQ 3: how do university scientists (Actor) measure the performance of innovative projects (Outcome)?

Some of the relevant literature (e.g. Chiesa & Frattini, 2007; Chiesa et al., 2007) has suggested that the selection of performance measurements for innovative projects should be associated with the structure and purpose of the projects, as discussed. However, literature on the selection of performance measurements for UICs, or innovative projects, from the university scientists' perspective is scarce. Therefore, in order to define what performance measurement implies from their point of view, the interviewees were asked whether and why the project outcome was considered as a success or a failure. Table 4.9 exhibits an overview of the findings of the inquiry from the university scientists' and industrial managers' perspectives. The project outcome of the investigated projects have been categorised into three groups – success, failure and ambiguous, according to the evaluations made by the interviewees.

Table 4.9: Measurements for Project Outcomes from the Exploratory Research Phase

Project	Outcome	Illustration	
		University scientist's perspective	Industrial manager's perspective
A	Success	"I would say this project was successful because I have done much more than what I had to do in according to the research proposal defined at the beginning. Also, the firm was happy with the results" (Scientist A)	"It was successful. … Professor Chen has done more than the research proposal stated" (Manager A)
C	Success	"This project was a successful one, as my collaborator [the firm] and the NSC were happy with the result which achieved the project objectives, and they have granted follow-up research funding for further research." (Scientist C)	"It was definitively successful, as the established project objective was achieved although this project did not come in on time and budget. But we were happy with the current outcome of this project." (Manager C)
D	Success	"… certainly, it was successful. This project went along according to the project plan, and all of laboratories involved, even the NSC, were satisfied with the outcomes although the budgets and time-span were exceeded. In addition, I would like to emphasise is that I have published SCI papers based on the outcomes of this projects" (Scientist D1) "…we have published, or been accepted for, several SCI papers based on the outcomes of this project, and we have been given another grant for a further research" (Scientist D2) "According to the outcomes of this project, such as efficiency, and benefits gained, such as, technology transfer and publications, I would define it as success. …, we have been granted funding for another three-year of research." (Scientist D3)	"I think it was a successful project because we [the firm] have obtained the knowledge and technologies that we wanted." (Manager D)
E	Success	"…, this project has not comprehensively achieved its objective, but my collaborator was happy with the current outcome. So, we have been granted follow-up research funding for its final objective. In addition, three SCI papers have been published. Based on these points of view, I would like to define this project as success." (Scientist E)	Data is not available
F	Success	"It was a success. We have developed the prototype of a vaccine that is to be tested for mass production. The marginal benefits obtained by carrying out this project are: training lots of students; accumulating invaluable data and experience; and publishing a few SCI papers." (Scientist F)	"I like collaborating with Professor Lin because he always tries to complete the projects on time and on budgets, and he is more than likely to make the maximum benefit for us [the firm]; of course, with Professor Lin this project was not different to previous collaborations. So, from my point of view, I would say it was a success project." (Manager F)

Table 4.9 (Continued)

J	Success	"It was a successful project because it met the objective on time according to our research proposal. Also, some of the outcomes have been published [in an SCI journal]" (Scientist J)	"This project can be evaluated as a successful one although it was slightly overran its time and budget. However, we [the firm] have got what we wanted. This is the point. (Manager J)
H	Failure	"We seemed to be too optimistic. This project did not go in the direction that we proposed, and even worse we [university scientist and the firm] have not benefited anything from this project. … The NSC has notified us that this project will be terminated, unless we can provide strong evidence about securing assess to the sources of the experimental materials" (Scientist H)	"Everything about the implementation of this project was a nightmare, such as overrunning on time and budget and not meeting our [the firms'] objectives … In fact, we [the firm] have been thinking of stopping this project, unless we can firmly assess to the experimental materials for this project." (Manager H)
B	Ambiguous	"…hard to say. Although this project has met its objective within the time limit, the productivity has not reached the commercial standard yet. … This project has not brought any SCI papers to me." (Scientist B1)	"In terms of the progress and cost of this project, I would say yes; however, it aimed to commercialise a laboratory result, and it has not achieved this purpose yet." (Manager B1) "I evaluated this project as not successful yet because it has not achieved its aim – commercialisation" (Manager B2)
G	Ambiguous	"This project was basic research, and its aim was to discover scientific knowledge in order to understand the initiation mechanism of cancer X. So, it is difficult to define its success or failure at this stage because we [university scientists and the firm] have not found a reasonable mechanism to be able to draw a conclusion or hypothesis. However, I think it may be seen as successful, as we have met the project objectives, been granted another research funding for a further study, and published three papers related to this project." (Scientist G1) "We [university scientists and the firm] have published three SCI papers, and have been granted follow-up research funding for further study; therefore, I would like to define it as a success." (Scientist G2)	"In terms of outcomes, this project can be defined as a success, but, in terms of progress and cost, it was not acceptable. So, I would not say this project was successful." (Manager G)

4.4.1. Scope, Cost and Time

Drawing from Table 4.9, the achievements of meeting cost, time and scope objectives were salient criteria for defining the project as a failure or a success from the participants' perspectives. This was particularly true from the university scientists' perspective. For example, a university scientist in project D stated:

> *"… certainly, it was a successful one. This project went along according to the project plan, and all of the laboratories involved, even the NSC, were satisfied with the outcomes, even though the budgets and time-span were exceeded, because the same research team has been granted a follow-up research funding for the further studies, that is, the NSC and industrial partners were satisfied with the outcomes. In addition, I would like to emphasise that three SCI papers have been published and accepted, based on the findings of this project. The point to be made here is that the successful results of an innovative project often bear no resemblance to the original research plan [research proposal], so other criteria are needed." (Scientists D1)*

In comparison, as project B illustrates, although the project had met the pre-stated objective within the planned time-span and budget, the PI (principal investigator) of the project evaluated it as being comprehensively unsuccessful, because it was still struggling to improve productivity in order to achieve its final aim, i.e. commercial mass production. The PI claimed: "… hard to say. Although this project has met its objective within its time and budget, the productivity has not reached the commercial standard yet" (Scientist B). This statement echoes the statement made by Scientist D1, and these two statements reinforce the fact that the measurements related to time, cost and scope are too narrow to be those used for the innovative projects involving university scientists.

Responses from industrial managers also indicated that only using 'traditional' PM perspectives to measure innovative projects is considered restrictive. For instance, project D, being defined as successful, reported that the progress of the project did not achieve its objective within the planned time-span and budget, but Manager D assessed it as a success, because the collaborative firm "has obtained the knowledge and technologies that we [the firm] wanted" (Manager D). Moreover, project B, being categorised as ambiguous, and showed that the outcome of the project in terms of project progress was satisfied, by both university scientist and the industrial manager. However, the latter did not evaluate this project as successful, because it had not achieved its final aim, i.e. launching the outcomes of the project onto the market. As Manager B1 stated: "In terms of the progress and cost of this project, I would say yes;

however, this project aimed to commercialise a laboratory result, but it has not achieved this yet" (Manager B1).

The findings above show that despite the emphasis of PM scholars and practitioners on general success criteria (e.g. scope, time and cost), the majority of the university scientists did not find these adequate. More comprehensive dimensions of performance measurements for innovative projects is required (Chiesa & Frattini, 2007; Chiesa et al., 2007). A university scientist in project D explained:

> *"… We are talking about carrying out university-industry R&D collaborations [UIC], which are likely to have uncertain outcomes and to be unstructured, and monitored by all stakeholders, e.g. the funding bodies and the top management of the organisations; therefore, we are within the variance limits proposed by stakeholders, and also things like stakeholder satisfaction is very important because if they [the firm] are really not happy with the outcomes of the projects, they will cut research funding. That is, they are more likely to focus on time and budget, but I believe this is not enough to evaluate an innovative project. There are other factors which are more important that should be applied in an evaluation. For example, the contributions of such innovative projects to both science and the economy should be more important than time and budget, as most of them deliver something which is fundamentally valuable to the end users." (Scientists D1).*

Whilst time, cost and scope may be perceived as being too narrow to be the only performance measurements for innovative projects that university scientists are involved in, this study takes this into account in accordance with the interview statements, particularly form the industrial managers' perspective. As can be seen in projects C, D, and G, meeting project objectives within proposed schedules and budgets was employed by them to evaluate the project performance. This refers to the 'efficiency' and 'time' dimensions for selecting performance measurements, as discussed in Chapter Two (Chiesa & Frattini, 2007; Chiesa et al., 2007). For instance, an industrial manager in project G claimed: "In terms of outcomes, this project can be defined as a success, but, in terms of progress and cost, it was not acceptable. So, I would not say this project was successful" (Manager G).

In addition, the university scientists appear to have started taking these two dimensions into account. One university scientist, for example, in project D stated: "According to the outcomes of this project, such as efficiency, technology transfer and publications, I would define it as success" (Scientist D3); moreover, the university scientist in project A explained that he always paid attention to the efficiency when conducting UICs, because he understood that time was an important factor related to business revenue. He stated:

> *"R&D projects [innovative projects] are very uncertain, making it hard to predict how much time I will take to achieve the proposed project objective. However, as most of my collaborators are small and medium-sized firms, I have to think about their survival and help them to make a profit as soon as possible. Therefore, I always pay attention to the efficiency when doing UI R&D collaboration." (Scientist A)*

Regarding the budget, the university scientists interviewed agreed that it should be one of the control tools employed by top management and funding bodies to control the direction of innovative projects (e.g. NPD) (e.g. Bart, 1993; Omta & de Leeuw, 1997). However, regarding the interviewees from the universities only in three of the projects investigated for this research was 'budget' perceived as a criterion for assessing their performance (see Table 4.10, below). Therefore, because controlling the budget is not seen to be within the remit of the university scientists, it is not included as an efficiency factor. Hence, this study only places meeting the project objective within the time limit into the 'efficiency' category, because, from university scientists' perspective, efficiency is viewed as equivalent to 'conducting project in time'. 'Meeting Project Objective within Schedule' (MOPS) is therefore identified as a performance measurement for innovative projects from the university scientists' viewpoint, and it will be employed as a variable in the explanatory research.

4.4.2. Measurements from a Broader Perspectives

Stakeholder satisfaction

Based on the interview statements, all the interviewees claimed that the perspective of 'stakeholder satisfaction' was employed by them to determine the success of innovative projects, and this was determined by two variables – Achieving Objectives (AO) and Continuously Receiving Research Funding (CRRF).

As can be seen in Table 4.9, pre-stated project objectives were employed by all of the projects investigated. For example, both the university scientist and industrial manager in project A evaluated the project as success, in that it met the objectives, which were stated in the research proposal. The former stated: "I would say this project was successful because I have done much more than what I had to do according to what the research proposal defined at the beginning" (Scientist A). Furthermore, the latter asserted: "It was successful. … Professor Chen has done more than the research proposal defined" (Manager A). In comparison project F was evaluated as a failure, because its project objective was not met. The university scientist in the project stated: "the project did not go in the direction that we had proposed" (Scientist F). These views are concerned with whether the results of the innovative projects being undertaken by university scientists could have met the project objectives, as defined in the research proposals. Thus, Achieving Objective (AO) has been identified in this study as a performance measurement for evaluating innovative projects, and it will be a variable in the next phase.

Moreover, most of university scientists interviewed claimed that satisfying stakeholders contributes to receiving follow-up funding for further research. The university scientist in project E, for instance, asserted: "…this project has not comprehensively achieved its objective, but my collaborator was happy with the current outcome. So, we have been granted follow-up research funding for its final objective …" (Scientist E). Moreover, the university scientist in project C claimed: "This project was a successful one, as my collaborator [the firm] and the NSC have granted follow-up research funding" (Scientist C), indicating that the stakeholders of these two projects were satisfied with the outcomes. Even the university scientist involved in the project defined as a failure held a similar view on the use of the performance measurement. For example, in project H, defined as a failed project, funding bodies were not satisfied with the performance; as a result, the funding bodies, i.e. the NSC and the firm, were thinking about stopping its research grant. In fact, this project was terminated. The university scientist in the project stated: "We seemed to be too optimistic. This project did not go in the direction we proposed, and even worse we have not benefited anything from it" (Scientists H). Moreover, the industrial manager in project H claimed:

> *"Everything about the implementation of this project was a nightmare, such as overrunning on time and budget and not meeting our [the firms'] objectives. … In fact, we [the firm] have been thinking of stopping this project, unless we can firmly assess to the experimental materials for this project." (Manager H)*

Furthermore, he further explained:

> *"If our [the firm's] resources were unlimited, we [the firm] would have invested in this project. Unfortunately, in these days of greater accountability than was the case in the past it is*

> *probably necessary to set time and funding limits to particular parts of such collaborations [innovative projects] and to say that if we [the firm] have not found anything that is more likely to contribute to our benefit, e.g. increasing sales and technological capabilities, we will stop and wait for some promising results." (Manager F)*

This measurement of the level of ongoing funding is termed in this study as Continuously Receiving Research Funding (CRRF).

Contribution to value

Based on projects B, C, D, E, F, G, J and H in the exploratory research, publishing SCI (Scientific Citation Index) papers, from the university scientists' perspective, was viewed as a factor employed for measuring the performance of the innovative projects that they were involved with. Such a phenomenon is strongly linked, in their eyes, to their professional status, their academic careers (Cohen et al., 1999b; Miller, 1986), and their capabilities of delivering innovative projects (Herbertz & Muller-Hill, 1995). For instance, a university scientist in project G stated:

> *"… no matter what innovative project I am undertaking, I am usually eager to investigate further the unexpected but interesting findings emerging from the experiments that I am conducting. … I will not undertake any UI R&D collaboration if I cannot take advantage of doing these projects in terms of academic matters, that is, the outcomes of the projects can be published in SCI papers, because SCI papers are highly associated with my academic career." (Scientist G2)*

Not only the university scientists emphasised SCI papers as a measurement for assessing innovative projects, but also industrial managers recognised their function. They acknowledged that the publishing of SCI papers could be seen as an indicator to predict the level of achieving project objectives, and of providing high quality products and services from a project outcomes (Boffo, Chave, Kaukonen, & Opdal, 1999; Herbertz & Muller-Hill, 1995; Narin, Hamilton, & Olivastro, 1997). Also, such a performance measurement could attract university scientists to joining UICs. For instance, the industrial manager in project G claimed:

> *"…they [university scientists] have not changed their mindsets yet, which seem to still remain in the same state as when they are undertaking academic research projects. No matter what kind of research projects they carry out, they firstly think about science and publications, as these are highly associated with their academic status and promotion. … Actually, we [the firm]*

are more likely to take advantage of publishing SCI papers because sharing co-authorship of SCI papers indicates our capabilities to perform our business well. So, we tend to be open regarding the publishing of SCI papers because in addition to the advantages mentioned earlier, allowing the publication of the results of the projects motivates them [university scientists] to participate in UI R&D collaborations. However, we [the university scientists and the firm] have to discuss the contents of the papers to be published, concerning the matters related to intellectual property protection." (Manager G)

In addition to SCI papers, some university scientists and industrial managers defined the success of the project by whether they benefited or not by carrying them out, i.e. value from the projects. For instance, a university scientist in project D, defined as a success, stated: "…value from this project, such as, technology transfer and publications, I would define it as a success …" (Scientist D3). In addition, the university scientist in project H, defined as failure, asserted: "… even worse, we [university scientist and the firm] have not benefited anything from this project" (Scientist H). In addition, some of industrial mangers take the same view to evaluate the success of the projects. The industrial manager in project D claimed: "… we [the firm] have obtained the knowledge and technologies that we wanted" (Manager D).

Although some university scientists and industrial managers acknowledged other values, e.g. technologies and knowledge transferring, this study does not adopt these to be the criteria for measuring the performance of innovative projects that university scientists are involved in. That is, only the Numbers of SCI Papers published (SCI) will be used as one of the variables employed in the explanatory research phase of this study. This is based on the fact that the other values gained from undertaking innovative projects have been converged, e.g. learning, technology transferring etc., and these were only employed in three of the projects investigated (see Table 4.10).

In sum, based on the interview statements, this study identified four measurements for assessing the performance of innovative projects from the university scientists' perspective. These measurements are: Meeting Objective within Proposed Schedule (MOPS), Achieving Objective (AO), Continuously Receiving Research Funding (CRRF), and Numbers of SCI Papers published (SCI). The use of these by the university scientists and industrial managers in the projects investigated is demonstrated in Table 4.10.

Table 4.10: The Exhibition of Criteria Employed in the Exploratory Research

Project	Outcome	Criteria applied in exploratory research					
		Efficiency		Stakeholder Satisfactions		Value	
		MOPS	Budget (cost)	CRRF	AO	SCI	Other benefits (e.g. knowledge transferring, learning)
A	Success	V		V	V		
C	Success	V	V	V	V	V	
D	Success	V	V	V	V	V	V
E	Success				V	V	
F	Success	V			V	V	V
J	success	V			V	V	
H	Failure	V		V	V	V	V
B	Ambiguous	V			V	V	
G	Ambiguous	V	V	V	V	V	
		88.89%[a]	33.33%	55.56%	100%	88.89%	33.33%

V = Applied; Blank = Not applied

[a] the percentage indicates the extent of the performance measurement employed by the projects interviewed; calculated by that the numbers of projects interviewed that applied the measurement / the total numbers of the project interviewed.

Moreover, Table 4.11 shows a comparison of the findings in the existing literature and the exploratory research phase in this study. It also gives an overview of the main criteria to be used in the questionnaire as part of the explanatory research phase of this study.

Table 4.11: A Comparison between Project Performance Measurements Identified in the Literature Review and in the Exploratory Research

Factors identified in literature	Factors from exploratory research	Criteria for explanatory research
Implementation of the project Project efficiency	Efficiency: Meeting objectives on time (e.g. all projects investigated except project E), or budget (C, D and G)	MOPS
Stakeholder satisfaction; impact on stakeholder; effectiveness	Stakeholder satisfaction: CRRF (e.g. projects A, C, D, G and H); AO (e.g. all projects)	CRRF and AO
Perceived value of the project Business and direct success	Value from the project: SCI paper (e.g. projects B, C D, E, F, G, H and J); other benefits, e.g. staff training; experience learning; knowledge accumulation (e.g. projects A, G and H)	SCI

Project management literature tends to suggest that the project outcome is defined by scope, cost and time. However, as the findings show, the focus on only scope, cost and time, as suggested by most of the interviewees, is too narrow. As a result of the findings in this study, the measurements of the project performance of the innovative projects being undertaken by the university scientists, from the interviewees' point of view, include several main criteria to be employed in the explanatory research of this study (see Table 4.11): MOPS; AO; CRRF; and SCI. In addition, these four performance measurements for innovative projects have led to the re-illustration of the framework, shown in Figure 4.4.

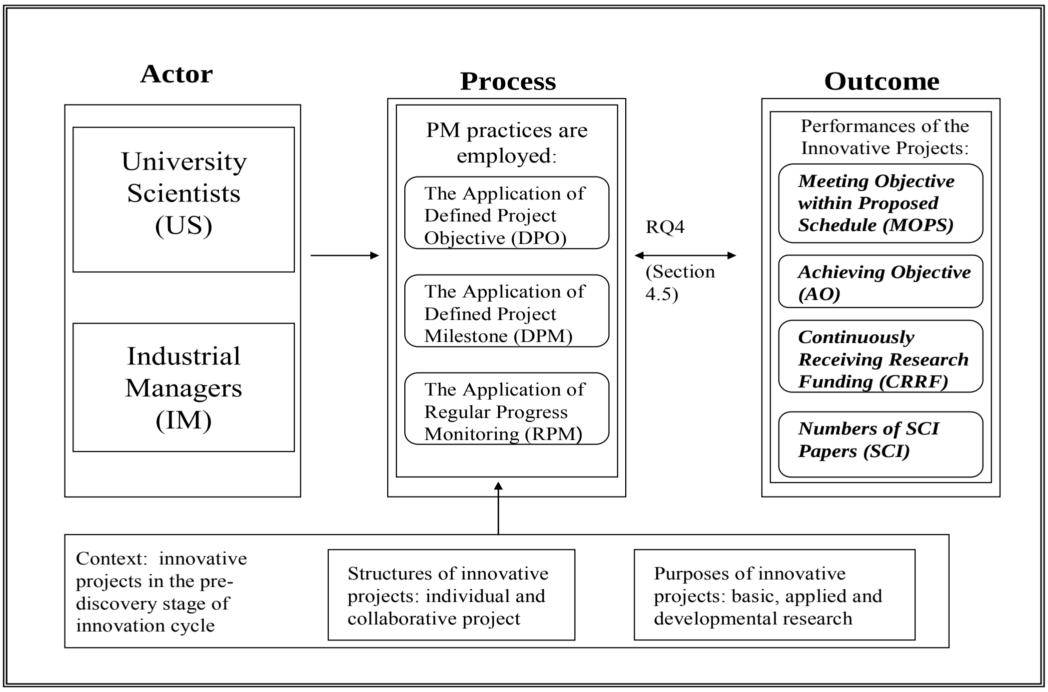

Figure 4.4: The Framework Incorporating the Variables Identified for Process and Outcome Constructs

4.5. Effectiveness of Employing Project Management Practices

This section shows the effect of the employment of the PM practices identified above on the performance of innovative projects, from university scientists' point of view. What is worth noting here is that the industrial managers' viewpoint related to this issue is excluded. This is because most of them were not involved in the execution stage of the project life cycle (e.g. Tables 4.3, 4.5 and 4.7). In addition, some scholars have argued that PIs (i.e. university scientists in this study) would positively contribute to the management in ways that help to maximise the performance of innovative project (e.g. Afuah, 1998; Cordero et al., 2004; Katz, 1997). This should not affect the quality of the findings, regarding the relationship between the employment of the PM practices identified, and the performance of the innovative projects in terms of the four criteria highlighted. This is because the researcher applied a 'pattern match' process to develop the relationship, and thus, the quality of the findings can be ensured, as discussed in Section 3.7.

The measurements and the PM practices to be employed to explore the relationship between the levels of the employment of the PM practices highlighted and the performance of innovative projects, being undertaken by the university scientists have been highlighted and presented in Figure 4.2 above. In order to explore in more detail, the university scientists were asked to answer the questions about the effectiveness of the use of each of these PM practices on the performance of their project. Thus, the Research Question 4 formulated in Chapter One can be addressed.

- RQ 4: what impacts does the use of PM practices (Process) have on the performance of innovative projects (Outcome)?

4.5.1. Effects from Defined Project Objective

Table 4.12 presents the data on the perceived effect of the use of DPO on the performance of innovative projects from the university scientists' perspective.

Table 4.12: The Summary of the Effects of the Employment of DPO on the Performance Innovative Project

Project	Outcome	Criteria for measuring the performance of the innovative project			
		Efficiency	Stakeholder satisfactions		Benefit gained
		MOPS	CRRF	AO	SCI
A	Success	V-M	V-H	V-H	V-L
C	Success	V-M	V-H	V-H	V-M
D	Success	V-M	V-H	V-H	V-L
E	Success	V-L	V-M	V-M	X
F	Success	V-M	V-H	V-H	V-L
J	Success	V-M	V-M	V-H	V-L
H	Failure	V-L	V-M	V-M	X
B	Ambiguous	V-L	V-H	V-M	V-L
G	Ambiguous	V-L	V-H	V-H	V-L
Average Effect[a]		Medium	High	High	Low

V-H = Applied and High Effect; V-M = Applied And Medium Effect; V-L = Applied and Low Effect; X = No Effect

[a] the extent of the average effect is determined by the researcher of this study in accordance with the extent of the effects of the use of PM practices on the performance of innovative projects.

As it can be seen in Table 4.12, the degrees of the effect of the employment of DPO on the performance of collaborative projects that the university scientists are involved in are different. Moreover, based on the qualitative data, in terms of CRRF and AO, six out of nine projects investigated claimed to view these as highly related to the use of DPO. Regarding MOPS, the application of DPO moderately contributed to about half of the projects investigated, and little to the rest. With respect to SCI, the university scientists mostly perceived the use of DPO contributed very little to the numbers of SCI publications.

The rationale of these findings are that DPO is more likely to function as a strategic objective of the projects (Salomo et al., 2007), and to maintain them on the original track, heading towards the objectives, ultimately attaining stakeholder satisfaction. This is consistent with PM theory of the application of DPO, as such employment is seen as a tool to assist project managers in achieveing pre-stated project objectives on time (e.g. PMI, 2004), eventually satisfying stakeholders' requirements (e.g. Dvir & Lechler, 2004). Then, the latter will grant further research funding, according to the interview statements gathered from university scientists. Most of university scientists interviewed claimed that there was a great effect of employing DPO on CRRF and AO.

4.5.2. Effects from Defined Project Milestones

Table 4.13 presents the data on the effect of the employment of DPM on the performance of innovative projects from the university scientists' perspective.

Table 4.13: The Summary of the Effects of the Employment of DPM on the Performances of Innovative Project

Project	Outcome	Criteria for measuring the performance of the innovative project			
		Efficiency	Stakeholder satisfactions		Benefit gained
		MOPS	CRRF	AO	SCI
A	Success	V-M	V-H	V-H	V-L
C	Success	V-H	V-H	V-H	V-M
D	Success	V-M	V-H	V-H	V-L
E	Success	V-M	V-M	V-M	X
F	Success	V-H	V-H	V-H	V-L
J	Success	V-M	V-M	V-H	V-L
H	Failure	V-H	V-H	V-H	X
B	Ambiguous	V-M	V-H	V-M	V-L
G	Ambiguous	V-M	V-H	V-H	V-L
Average Effect[a]		Medium	High	High	Low

V-H = Applied and High Effect; V-M = Applied And Medium Effect; V-L = Applied and Low Effect; X = No Effect

[a] the extent of the average effect is determined by the researcher of this study in accordance with the extent of the effects of the use of PM practices on the performance of innovative projects.

As can be seen in Table 4.13, the level of the influence of the employment of DPM is similar to the application of DPO. The influence of the application of DPM is still highly associated with the stakeholder satisfaction (i.e. CRRF and AO), as compared with the application of DPO. In particular, the degree of the effect of the employment of DPM on MOPS appears to be higher than the degree of the use of DPO. This is based on the fact that the degrees of the effects of the employment of DPM are mostly at either high or medium levels; however, the effects of the use of DPO are mostly at either medium or low levels (see Tables 4.12 and 4.13). This observation indicates that DPM is more likely to be employed in innovative projects by the university scientists, to make project progress (e.g. Scientist C's statement). That is to say, employing DPM is usually associated with the use of RPM, and their function is to help team members to succeed in their research. Consequently, this is likely to increase the possibility of achieving the project objective within the agreed time-span (MOPS), and the level of stakeholder satisfaction, (e.g. the effectiveness of the projects) (e.g. Blindenbach-Driessen & van den Ende, 2006; Dvir & Lechler, 2004).

4.5.3. Effects from Regular Progress Monitoring

Table 4.14 presents the data on how the university scientists viewed the use of RPM influences the performance of the innovative projects in which they are involved.

Table 4.14: The Summary of Effects of the Employment of RPM on the Performance of the Innovative Projects

Project	Outcome	Criteria for measuring the performance of the innovative project			
		Efficiency	Stakeholder satisfactions		Benefit gained
		MOPS	CRRF	AO	SCI
A	Success	V-M	V-H	V-H	V-M
C	Success	V-H	V-H	V-H	V-H
D	Success	V-H	V-H	V-H	V-H
E	Success	V-H	V-M	V-M	V-M
F	Success	V-H	V-H	V-H	V-H
J	Success	V-H	V-M	V-H	V-H
H	Failure	V-H	V-H	V-H	V-M
B	Ambiguous	V-M	V-H	V-M	V-M
G	Ambiguous	V-H	V-H	V-H	V-M
Average Effect[a]		High	High	High	Medium

V-H = Applied and High Effect; V-M = Applied And Medium Effect; V-L = Applied and Low Effect; X = No Effect

[a] the extent of the average effect is determined by the researcher of this study in accordance with the extent of the effects of the use of PM practices on the performance of innovative projects.

In comparison with the employment of DPO and DPM, the application of RPM appears to contribute to all of the performance criteria highlighted. Furthermore, the university scientists interviewed stated that holding *regular* meetings considerably contributed towards meeting the project objectives within the agreed time-span (MOPS), and to receiving follow-up research funding (CRRF). Moreover, the level of its influence on the publishing of SCI papers increased, from low to medium. This increased level may be attributed to the improvement in the effectiveness and efficiency of conducting innovative projects, by the employment of RPM. A university scientist in project D explained:

> *"We met regularly for progress report mainly; in addition, we discussed the results and progress of the experiments from time to time for determining the next step when undertaking experiments or solving problems delaying project progress. … Thus, an innovative project can be undertaken faster and better. In other words, a research project can achieve its objective faster, and there is a higher possibility of publishing the outcomes." (Scientist D1)*

4.5.4. An Overall View of the Effects of the Employment of Project Management Practices on Performance

Drawing from Tables 4.12, 4.13 and 4.14, it can be seen that the applications of the PM practices highlighted positively contribute to the performance of innovative projects in terms of MOPS, AO, CRRF, and SCI. The following statement made by a university scientist in project D gives a summary of the effects of the employment of these three practices on the performance of innovative projects.

> *"I always asked myself and researchers supervised by me to understand why we undertook this project, what we should do and when we should achieve certain progress. In other words, project objectives and a set of control points [milestones] have to be determined before starting. Nevertheless, these objectives and control points should be clear and reasonable. During the project, we had arranged regular meetings in order to check the project progress and to find possible solutions to any problem that may have happened during the projects. This is the way I am used to monitoring project progress. It is quite useful to make project progress. Actually, I would like to recommend it because the environment in which we are working is really uncertain, and achieving project objectives is always a time-pressured intensive task." (Scientist D1)*

The findings of the exploratory research indicate that the university scientists believed that the employment of RPM made the most contribution to the performance of innovative projects, in terms of the four criteria identified. This was followed by the use of DPM; the least contribution was made by the application of DPO. Moreover, in general, the effectiveness of the employment of the PM practices was mostly on AO and CRRF, moderately on MOPS, and hardly affected SCI. In fact, only employing RPM was viewed as a contributor to SCI. Furthermore, the contributions of the uses of DPO and DPM were more likely to enhance the 'stakeholder satisfactions' category, rather than improve efficiency. The findings of the exploratory research are partially inconsistent with traditional PM theory, in which it is argued that the use of PM practices ensures the 'efficiency' of the delivery of projects towards success (e.g. Dvir & Lechler, 2004; PMI, 2004). Table 4.15 displays a summary of the qualitative findings of the effects of the employment of the PM practices highlighted on the performance of the innovative projects, in which the university scientists were involved, in terms of the four performance criteria identified.

Table 4.15: Summary of the Qualitative Findings of the Employment of the PM Practices on the Performance of the Innovative Projects*

PM Practice	Extent of the application of PM practices	Performance criterion	Extent of the influence on performance
		MOPS	Medium
DPO	Between Medium and High	AO	High
		CRRF	High
		SCI	Low
		MOPS	Medium
DPM	Medium	AO	High
		CRRF	High
		SCI	Low
		MOPS	High
RPM	High	AO	High
		CRRF	High
		SCI	Medium

* this table is developed based on the qualitative data gathered by this study

Figure 4.5 illustrates the qualitative findings which have been presented in Sections 4.2-4.5.

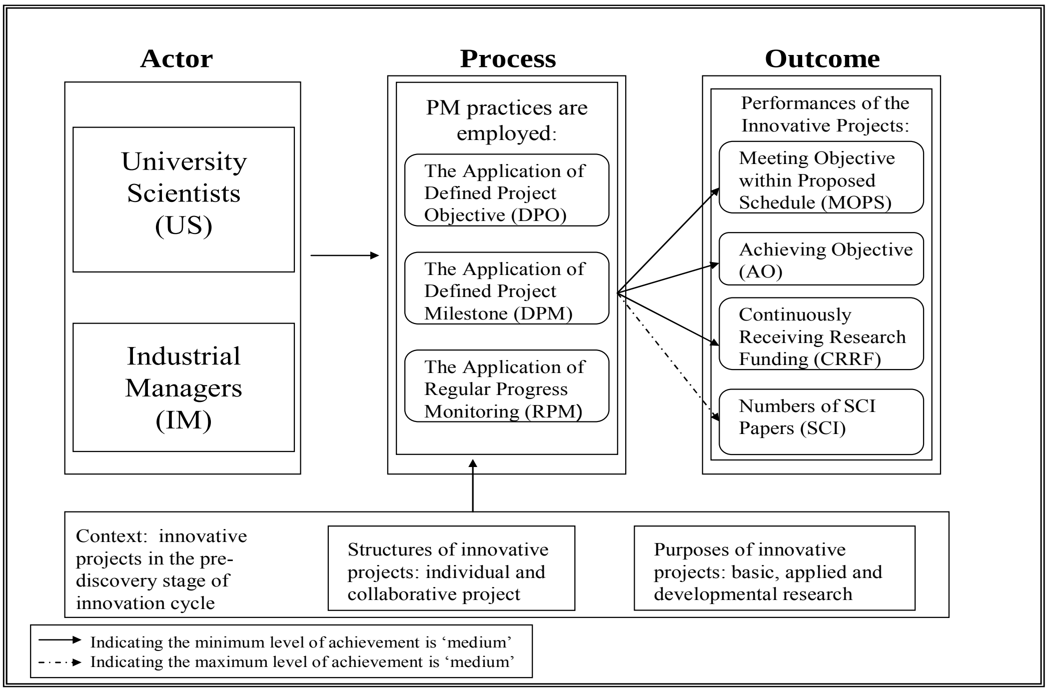

Figure 4.5: Findings of the Exploratory Research Phase

4.6. Research Questions Revisited

In the exploratory phase, based on university scientists' point of view, this study has identified three PM practices, i.e. DPO, DPM and RPM, as the variables of the process construct in the conceptual framework. In addition, four measurements, i.e. MOPS, AO, CRRF and SCI, have been chosen for assessing the performance of the innovative projects in which university scientists are involved. These variables are to be employed in the explanatory research stage, in order to test whether the findings from the exploratory phase would apply to a wider population of university scientists within the boundaries of this study. Thus, the research questions asked in this phase have to be modified when they are employed in the explanatory phase. Therefore, this study posits that the research problem for the explanatory research phase is:

- How do university scientists employ DPO, DPM and RPM in managing innovative projects, and what are the effects of this usage on the performance of such projects?

In order to provide a more holistic understanding for the problem above, the research questions addressed in the exploratory phase are revised to:

- RQ 1.1: to what extent do university scientists (Actor) employ DPO, DPM and RPM (Process) in managing innovative projects?

- RQ 2.1: how do the structure and purpose of innovative projects impact on the levels of employment of DPO, DPM and RPM (Process) by university scientists (Actor)?
- RQ 3.1: to what extent do innovative projects undertaken by university scientists achieve the performance criteria of the projects, in terms of MOPS, AO, CRRF and SCI (Outcome)?
- RQ 4.1: what impacts does the employment of DPO, DPM and RPM (Process) have on the performance of innovative projects in terms of MOPS, AO, CRRF and SCI (Outcome)?

In addition, university scientists will be the only element in the Actor construct, as mentioned, university scientists are usually the PIs of the innovative projects established in the pre-discovery stage of the innovation cycle, and thus they are most likely linked to the management of the projects in which they are involved (e.g. Afuah, 1998; Cordero et al., 2004; Katz, 1997). Also, based on the interview statements gathered from the industrial managers, they were hardly ever involved in the execution stage of the project life cycle. Therefore, industrial managers are excluded in the explanatory phase. That is to say, the survey conducted in the next phase is focused on investigating how university scientists employ the PM practices identified. Based on the statements above, the conceptual framework for the explanatory phase is illustrated as Figure 4.6.

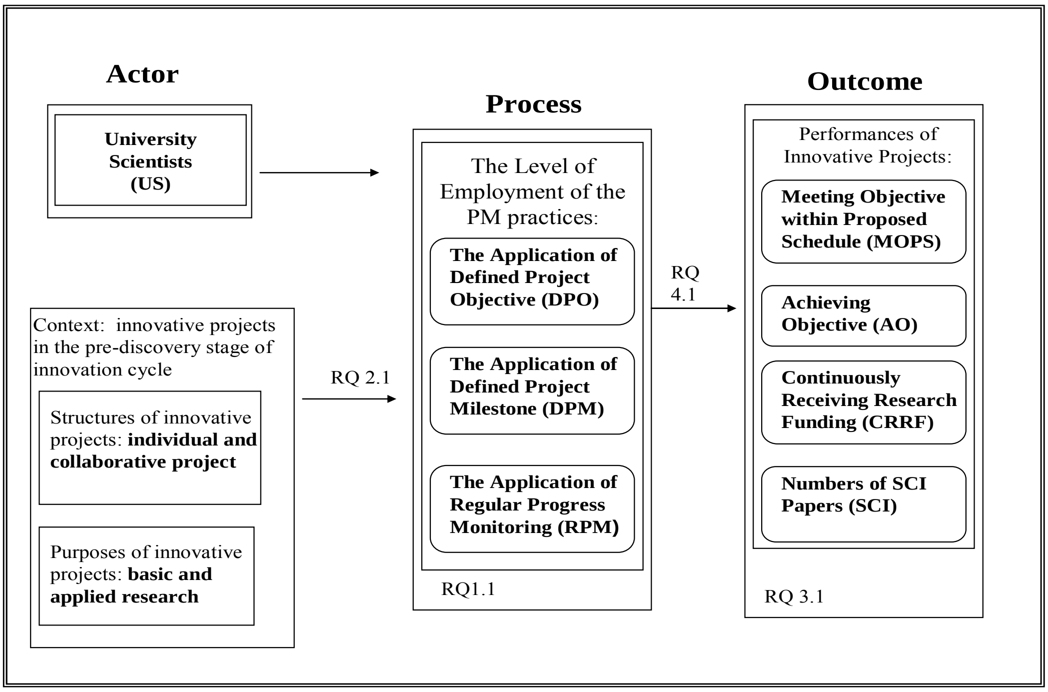

Figure 4.6: Conceptual Framework Revisited for the Explanatory Phase

4.7. Chapter Summary

The first phase of this study was designed to explore issues related to the research questions. The findings revealed that university scientists tend to employ three PM practices, i.e. DPO, DPM and RPM to manage innovative projects being undertaken by them. In addition, four performance criteria were highlighted. These are: MOPS, AO, CRRF and SCI. The relationships, from the university scientists' viewpoint, between the employment of these PM practices and the performance measurements have been constructed and presented in Table 4.15 above. Moreover, the structure and purpose of innovative projects have been identified as two contextual factors, which would influence the level of employment of PM practices in innovation projects by university scientists. The overall findings in this phase are illustrated in Figure 4.5. In addition, the findings in this phase are to be statistically examined in order to obtain a better understanding of the extent of employment of the PM practices and the impacts of such employment on the performance of innovative projects. As a result, a revised conceptual framework with the research questions is depicted in Figure 4.6.

Chapter Five: Explanatory Research

The findings of the exploratory research have qualitatively addressed the research questions formulated in Chapter One, and have provided a more comprehensive but concise conceptual framework. In order to examine whether the patterns identified in the exploratory research phase also apply to a greater number of innovative projects in the field of the biotechnology sector involving university scientists, a survey was conducted to address the revised conceptual framework and research questions. The revised research questions are as follows:

- RQ 1.1: to what extent do university scientists (Actor) employ DPO, DPM and RPM (Process) in managing innovative projects?
- RQ 2.1: how do the structure and purpose of innovative projects impact on the levels of employment of DPO, DPM and RPM (Process) by university scientists (Actor)?
- RQ 3.1: to what extent do innovative projects undertaken by university scientists achieve the performance criteria of the projects, in terms of MOPS, AO, CRRF and SCI (Outcome)?
- RQ 4.1: what impacts does the employment of DPO, DPM and RPM (Process) have on the performance of innovative projects in terms of MOPS, AO, CRRF and SCI (Outcome)?

Figure 5.1 again shows the conceptual framework and the revised research questions developed in the exploratory phase, which are to be statistically tested in the explanatory stage. This also indicates how this chapter is organised to address the revised research questions.

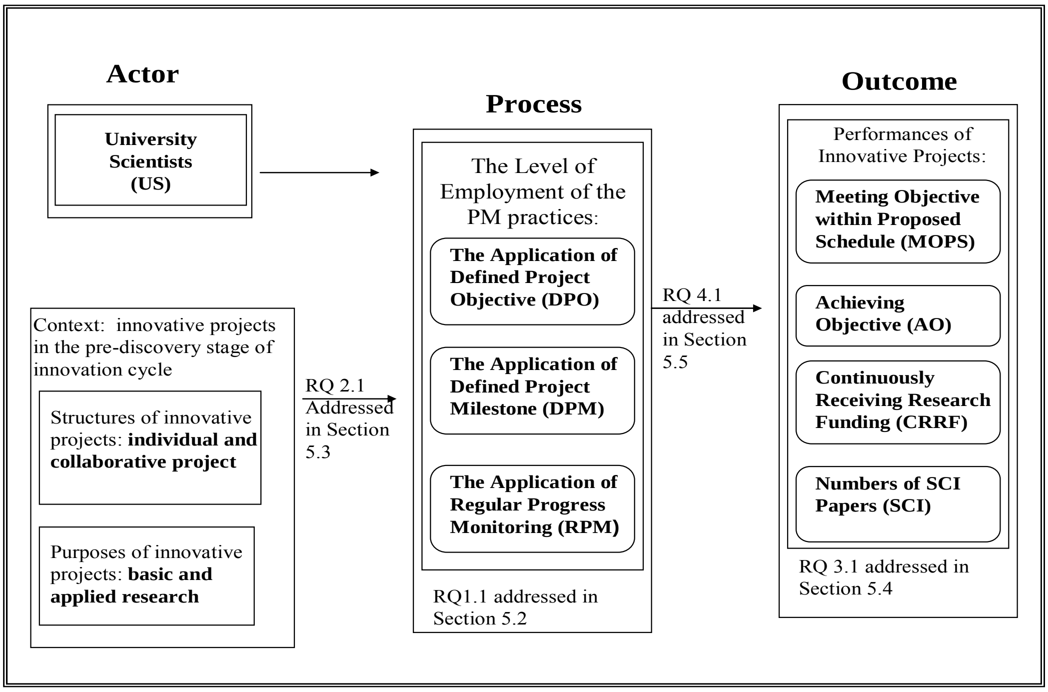

Figure 5.1: Conceptual Framework Developed in the Exploratory Phase to be Tested in the Explanatory Phase

This chapter presents the results of the explanatory data analysis. In this second phase of this study, the finalised questionnaire (see Appendix B) was distributed to university scientists who were working in biotechnology related departments of Taiwanese universities, through an electronic mail (Email) system. These departments can be categorised into a six sector classification in the biotechnology industry as defined by the MOEA (Luo, 2001; NSC, 2003). The estimated size of the population was around eight hundred university scientists. The survey data collection effort achieved an overall response rate of 19.6%, totalling 157 respondents from within the research boundaries. The quantitative data was processed using SPSS software version 14.0.

Section 5.1 presents the descriptive statistics. Section 5.2, examines to what extent the respondents employed the three PM practices identified, i.e. RQ 1.1. Section 5.3 analyses the influence of the structure (i.e. collaborative and individual) and purpose (i.e. basic research vs. applied research) of the innovative project, in which the university scientists are involved, on the level of employment of the PM practices identified, i.e. RQ 2.1. Section 5.4 explains to what extent the innovative projects being undertaken by university scientists succeed, in terms of the four performance measurements highlighted, i.e. RQ 3.1. Section 5.5 examines the relationship between the employment of PM practices and the performance of the innovative projects, i.e. RQ 4.1. Finally, section 5.6 summarises the findings of this phase.

5.1. Descriptive Statistics

In total, 157 respondents filled in the questionnaire. None of the questionnaires was viewed as invalid. Table 5.1 displays the background information of the respondents. With respect to the project fields in the biotechnology industry that the university scientists are involved in, none of the respondents is outside of the categories of the biotechnology industry, as defined by the MOEA (Luo, 2001; NSC, 2003).

Table 5.1: Descriptive Statistics of All of the Respondents

Contextual variable	N	Frequency	Percentage	Valid percentage (excluding non-applicable)
Project Field				
Biomedicine		74	47.1	50.7
Agriculture Biotechnology		39	24.8	26.7
Biopharmaceutical		12	7.6	8.2
Food Biotechnology		10	6.4	6.8
Medical Engineering		7	4.5	4.8
Bioinformatics		4	2.5	2.7
Sub-total	146		93	100
Non-applicable		11	7	
Total	157		100	
Project Structure				
Individual Projects		109	69.4	69.4
Collaborative Projects		48	30.6	30.6
Total	157		100	100
Project purpose				
Basic research		90	57.3	57.3
Applied research		57	36.3	36.3
Developmental research		10	6.4	6.4
Total	157			
Academic experience				
Full Professor		59	37.6	37.8
Associated Professor		48	30.6	30.8
Assistant Professor		49	31.2	31.4
Sub-total	156		99.4	100
Non-applicable		1	0.6	
Total	157		100	
Size in terms of amount of research funding (NTD)				
400,000 and below		18	11.5	11.8
400.001 – 700,000		44	28.0	28.8
700,001 – 1,000,000		51	32.5	33.3
1,000,001 – 1,300,000		21	13.4	13.7
1,300,001 – 1,600,000		6	3.8	3.9
1,600,001 – 1,900,000		6	3.8	3.9
1,900,001 and above		7	4.5	4.6
Sub-total	153		97.5	100
Non-applicable		4	2.5	
Total	157		100	
Size in terms of numbers of research team members				
5 and below		75	47.8	48.4
6 – 10		62	39.5	40.0
11 – 15		15	9.6	9.7
16 – 20		3	1.9	1.9
Sub-total	155		98.7	100
Non-applicable		2	1.3	
Total	157		100	

As can be seen in Table 5.1, only ten respondents claimed that the projects they referred to were developmental research, making statistical conclusions for this purpose difficult to draw. This study therefore focuses on the samples whose purposes are defined as basic research and applied research. That is to say, a survey dataset including only 147 questionnaires were analysed in the explanatory research to extend the findings attained in the first phase. Table 5.2 contains the descriptive statistics based on this dataset.

Table 5.2: Descriptive Statistics of Respondents for Data Analysed in this Phase

Contextual variable	N	Frequency	Percentage	Valid percentage (excluding non-applicable)
Project Field				
Biomedicine		70	47.6	50.7
Agriculture Biotechnology		38	25.9	27.5
Biopharmaceutical		9	6.1	6.6
Food Biotechnology		10	6.8	7.2
Medical Engineering		7	4.8	5.1
Bioinformatics		4	2.7	2.9
Sub-total	138		93.9	100
Non-applicable		9	6.1	
Total	147		100	
Project Structure				
Individual Projects		106	72.1	72.1
Collaborative Projects		41	27.9	27.9
Total	147		100	100
Project purpose				
Basic research		90	61.2	61.2
Applied research		57	38.8	38.8
Total	147		100	100
Academic experience				
Full Professor		54	36.7	39.7
Associated Professor		46	31.3	31.3
Assistant Professor		47	32	32
Total	147		100	100
Size in terms of amount of research funding (NTD)				
400,000 and below		16	10.9	11.1
400.001 – 700,000		41	27.9	28.5
700,001 – 1,000,000		48	32.7	33.3
1,000,001 – 1,300,000		21	14.3	14.6
1,300,001 – 1,600,000		6	4.1	4.2
1,600,001 – 1,900,000		5	3.4	3.5
1,900,001 and above		7	4.8	4.9
Sub-total	144		98	100
Non-applicable		3	2	
Total	147		100	
Size in terms of numbers of research team members				
5 and below		68	46.3	46.9
6 – 10		60	40.8	41.4
11 – 15		14	9.5	9.7
16 – 20		3	2.0	2.1
Sub-total	145		98.6	100
Non-applicable		2	1.4	
Total	147		100	

Table 5.2 displays the background information of the respondents within the research boundaries. With respect to the project fields, all of the respondents were in the categories of the biotechnology industry, as defined by the MOEA, because those who replied ‘non-applicable’ explained that their research covered a range of

the categories defined by the MOEA.

In terms of the structure of project (i.e. entitled as Project Structure in Table 5.2), 72.1% of the respondents were implementing individual (academic) innovative projects, and the rest indicated that they were conducting collaborative (commissioned) projects. In terms of the purpose of the projects, it was revealed that 61.2% of the respondents were focused on undertaking basic research projects, the others (38.8%) were involved in applied research.

The next contextual variable is the respondents' academic experience in terms of their academic titles, namely, Full Professor, Associate Professor and Assistant Professor, equivalent to Lecturer, Senior Lecturer and Professor in the United Kingdom, respectively. The respondents were almost equally distributed in the three groups.

On average, the projects that the respondents referred to were mostly seen as small projects in terms of the amounts of research funding, as 71.5% of the respondents indicated that they had received less than one million NTD, mostly ranging from 400,000 NTD to 1,000,000 NTD. In addition, the size of these projects in terms of the numbers of research team members was small. About half of the respondents indicated no more than five research team members were involved and another 40% of the projects involved six to ten research team members. That is, almost all of the respondents stated that the innovative projects they were involved in had no more than ten research team members.

Table 5.2 shows that the respondents involved in the explanatory phase covered all of the fields of the biotechnology industry, as defined by the MOEA (Luo, 2001; NSC, 2003), and the distribution of the respondents reflected that of the entire population of university scientists within the boundaries of this study, in 2004 (NSC, 2005). Thus, the level of reliability of the dataset employed in the explanatory research has been accepted.

5.2. The Employment of Project Management Practices

Three PM practices –Defined Project Objective (DPO), Defined Project Milestones (DPM) and Regular Progress Monitoring (RPM) – have been highlighted in the exploratory research stage. In addition, the university scientists interviewed stated that they employed these PM practices in managing innovative projects, but the levels of application varied. These findings were statistically tested in order to seek a more comprehensive generalisation, i.e. the RQ 1.1 (see Figure 5.1):

- RQ 1.1: to what extent do university scientists (Actor) employ DPO, DPM and RPM (Process) in managing innovative projects?

5.2.1. The Level of Employment of Defined Project Objective

Whilst project objectives are usually defined at the beginning of the research cycle, the defined project objectives (i.e. DPO) may be redefined during their life cycle. In order to test this finding on a wider population of university scientists, they were firstly asked whether project objectives were defined at the start of the innovative projects; secondly, they were asked to indicate to what extent they retained the DPO during the project life cycle. It is worth noting that the university scientists were asked to indicate to what extent they *never* redefine the defined objectives; therefore, the lower the level of agreement to this statement, the higher likelihood of the redefinition of the defined project objectives during project life cycle, and vice versa. Both of these two questions were used to measure this variable, as indicated by the respondents, on a five-point Likert scale (i.e. 5 being the Highest Extent and 1 being Not At All). Table 5.3 displays the frequency and percentage of the responses to these two measurements.

Table 5.3: The Responses to the Employment of DPO

Variable – DPO	Measurements[1]			
	I set up the project objective at the initial stage of the innovative project.		I never change the defined project objective during the life cycle of the innovative projects.	
N	147		147	
Mean	4.64		3.38	
Mode	5		3	
SD	.573		.954	
Response to…	Frequency	Percentage	Frequency	Percentage
Not at all	-	-	3	2.0
Low extent	-	-	22	15
Medium extent	7	4.8	55	37.4
High extent	39	26.5	49	33.3
The highest extent	101	68.7	18	12.2

[1] Scale: 1 = Not at all, 5 = the highest extent

Based on Table 5.3, the value of the Mean of the statement ("I set up the project objective at the initial stage of the innovative project") in the left column was 4.64, revealing that almost all of the actors, within the boundaries of this study, always established project objectives at the beginning of innovative projects. Indeed, when they were undertaking innovative projects, 68.7% of the respondents showed they always defined project objectives at the beginning of projects, and most of the rest of the respondents indicated that they usually tended to define project objectives, i.e. to 'High extent'. This confirms the findings of the exploratory analysis.

However, as stated in Chapter Four, DPO may be redefined during the project life cycle; therefore, university scientists were asked to indicate to what extent they *never* changed the defined project objectives during the project life cycle (i.e. the statement, "I never change the defined project objective during the life cycle of the innovative projects", in the right column in Table 5.3). It can be seen in Table 5.3, that DPO may be redefined by the university scientists during the project life cycle, based on the following distribution. 37.4% of the respondents indicated they may redefine project objectives during the project life cycle. 33.3% of the respondents indicted that they usually kept the DPO as a constant. 12.2% of the respondents responded that they never redefined the project objectives, i.e. to 'the Highest extent'. The rest of the respondents, 17%, showed that they were more likely to alter the defined project objectives during project life cycle compared to other respondents, because their responses were to 'Low extent' and 'Not at all'.

However, although the university scientists showed that they may redefine project objectives, they tended to retain the unchanged DPO throughout the project life cycle. This is because the greatest numbers of responses were for the 'Medium extent' (reflecting that the value of Mode is 3), and more respondents replied that they used a higher level of DPO, i.e. to 'High extent' and 'the Highest extent', than at lower levels, i.e. to 'Low extent' and 'Not at all' (reflecting that the value of Mean is 3.38). Consequently, it is claimed in this study that the degree of employment of DPO in innovative projects by university scientists is defined as at the 'medium-plus' level, i.e. slightly higher than the medium level.

5.2.2. The Level of Employment of Defined Project Milestones

Table 5.4 displays the results of the survey of whether the university scientists employed DPM in managing innovative projects, and to what extent. Similarly to the examination of the employment of DPO, two measurements (statements) were used. One statement was concerned with whether the university scientists established project milestones at the beginning of the projects, and the other statement was about whether they redefined the DPM during the project life cycle.

Table 5.4: the responses to the employment of DPM

Variable – DPM	Measurements[1]			
	I set up the project milestones at the initial stage of the innovative project.		I never change the defined project milestone during the life cycle of the innovative projects.	
N	147		147	
Mean	4.01		2.99	
Mode	4		3	
SD	.789		.972	
Response to…	Frequency	Percentage	Frequency	Percentage
Not at all	1	.7	9	6.1
Low extent	3	2.0	37	25.2
Medium extent	30	20.4	54	36.7
High extent	73	49.7	41	27.9
The highest extent	40	27.2	6	4.1

[1] Scale: 1 = Not at all, 5 = the highest extent

The findings regarding the level of employment of DPM were similar to those for the use of DPO. However, the level of the use of the former was lower. In other words, university scientists usually defined project milestones at the beginning of the projects (i.e. response to 'High extent'), but they could redefine them during the project life cycle (i.e. response to 'Medium extent'). This is based on the following observations. The values of the Mode and Mean of the first statement (left column in Table 5.4), 4 and 4.01, respectively, showed that most of the respondents defined project milestones when they were undertaking innovative projects. In addition, most of them might retain the original defined project milestones during the life cycle, as shown by the values of the Mode and Mean of the second statement (right column in Table 5.4), 3 and 2.99, respectively. Thus, the level of employment of DPM is defined in this study as being at the 'Medium' level.

In comparison, university scientists are more likely to establish DPO than DPM at the beginning of the projects, but they are more likely to redefine DPM than DPO during the project life cycle. This statement is supported by two paired sample *t* tests. The level of establishment is confirmed by Establishment DPO-DPM: $t(146)=10.225$; $p<0.001$, and the level of employment is supported by Employment DPO-DPM : $t(146)=6.602$; $p<0.001$.

In sum, the level of establishment of DPM by the university scientists is identified as at the 'High extent', and that of the employment of DPM is defined as at the 'Medium extent'. In other words, when the university scientists were undertaking innovative projects, they usually defined project milestones at the beginning of the projects, but they redefined the defined milestones at a moderate level, during the project life cycle. In addition, both of the levels of establishment and employment of

DPM are lower than those for DPO.

5.2.3. The Level of Employment of Regular Progress Monitoring

Table 5.5 below presents to what extent the university scientists employed RPM when they were undertaking innovative projects. They were asked to indicate to what extent they regularly monitored progress when they were carrying out such work.

Table 5.5: The Responses to the Employment of RPM

Variable – RPM	Measurements[1]	
	Please indicate to what extent you monitor project progress by regular meeting.	
N	147	
Mean	3.80	
Mode	4	
SD	.948	
Response to…	Frequency	Percentage
Not at all	2	1.4
Low extent	12	8.2
Medium extent	35	23.8
High extent	62	42.2
The highest extent	36	24.5

[1] Scale: 1 = Not at all, 5 = the Highest extent

Based on Table 5.5, the level of employment of RPM was defined as at the ‘Upper medium extent’ level, i.e. close to ‘High extent’. This is based on the facts that: (1) the value of the Mode was 4, showing that the greatest numbers of university scientists responded to the ‘High extent’; (2) the value of the Mean was 3.8, demonstrating, in general, the university scientists considerably employed RPM.

These findings are slightly different from those found in the exploratory research, in which, the use of RPM was highly emphasised, because only 24.5% of the respondents claimed that they always employed this PM practice. As mentioned, this difference may be attributed to the structure and purpose of the innovative projects. For example, the collaborative projects usually include outside team members, such as funding bodies and collaborators, and these outsiders are more likely to contribute to a higher level of application of RPM.

From the findings shown in sections 5.2.1 – 5.2.3, it can be seen that RQ 1.1 has been addressed. The levels of employment of DPO, DPM and RPM are defined as ‘Medium-plus’, ‘Medium’ and ‘Upper Medium’, respectively, based upon the values of the Modes and Means. Figure 5.2 shows these findings.

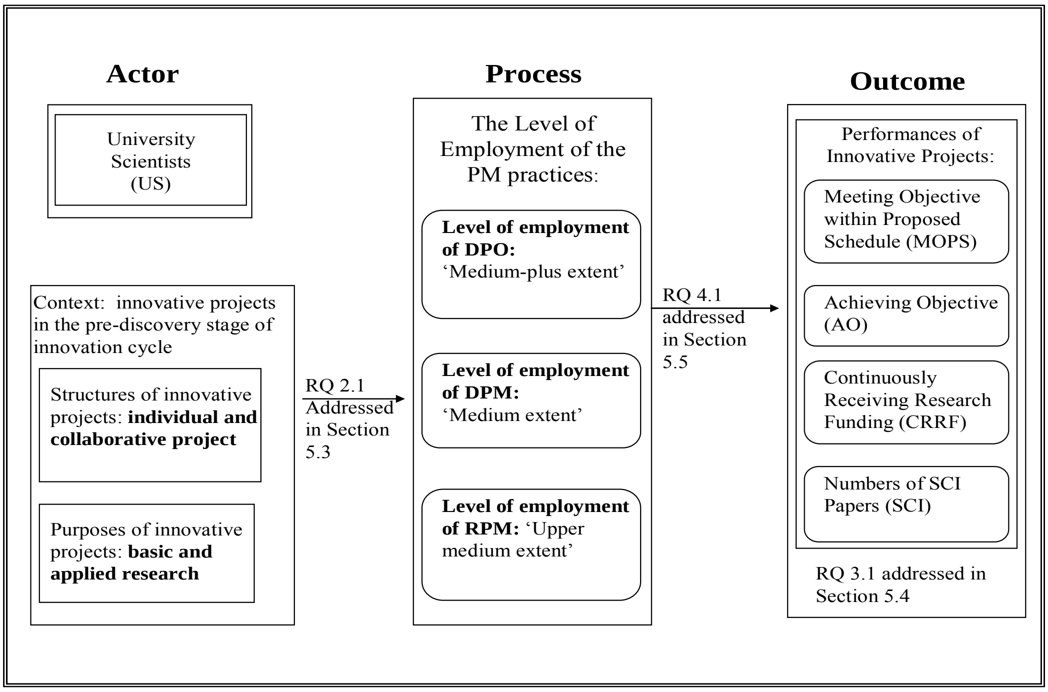

Figure 5.2: Levels of Employment of the PM Practices Identified

In addition, the level of application of RPM is higher than the application of DPO and the extent of the application of DPO is higher than the application of DPM, based on the results of the following paired sample *t* testes. The result of the first test is a DPO-DPM paired sample *t* test: $t(146)=6.602$, $p<0.001$. The second test is a DPO-RPM paired sample *t* test: $t(146)=-5.258$, $p<0.001$. The final one is a DPM-RPM paired sample *t* test: $t(146)=-13.537$, $p<0.001$.

5.2.4. Correlations of the Level of Employment of Project Management Practices

This section is used to determine the relationship between the levels of use of DPO, DPM and RPM by Pearson Correlation. Table 5.6 presents the results of the Pearson correlation.

Table 5.6: Correlations between the Levels of Employment of PM Practices Identified

Variable	DPO	DPM	RPM
DPO	1		
DPM	.707***	1	
RPM	.494***	.710***	1

N = 147
*** Correlation is significant at the .01 level

Based on Table 5.6, it can be seen that the levels of application of these three PM practices significantly correlate with each other. In addition, the degree of the correlation between the levels of applications of DPO and DPM is higher than the correlation between the degrees of employment of DPO and RPM. This indicates that when the level of application of DPO increases, the levels of employment of DPM and RPM also increase, and vice versa. Therefore, it is difficult to determine the effective direction of these variables (George & Mallery, 2003). Nevertheless, the university scientists' attention towards monitoring project progress is likely to lead to the applications of DPO and DPM, because most of those interviewed employed these two PM practices to check project progress, in order to obtain better effectiveness and efficiency of the innovative projects. Hence, this study claims that the employment of RPM would lead to the use of the other two PM practices, from the university scientists' perspective. However, such a suggestion cannot be confirmed in this study, as the tasks for the confirmation of this are outside the research framework.

As the degrees of applications of these three PM practices are highly correlated with each other, the problem that may be caused by co-linearity should be avoided. This can be achieved by using a "stepwise" method in the regression examination, when the regressions employed to examine the influences of the applications of these three PM practices on the performance of the innovative projects are being conducted.

5.3. Influences on the Employment of Project Management Practices from the Structure and Purpose of Innovative Project

This study suggested the structure and the purpose of innovative projects were likely to influence the level of application of PM practices by university scientists, and this was supported by the qualitative findings of the first phase. In order to examine whether these findings could be employed in a broader population of university scientists within the boundaries of this work, they were statistically tested in this stage. Therefore, the Research Question 2.1, illustrated in Figure 5.1, was formulated in Chapter Four as:

- RQ 2.1: how do the structure and purpose of innovative projects impact on the levels of employment of DPO, DPM and RPM (Process) by university scientists (Actor)?

This section will present the result of these examinations.

In the explanatory phase, two cross-tabulation analyses were conducted. One analysis was on the structures of the innovative projects and the levels of employment of the PM practices highlighted; the other one was on the purposes of such projects and the degrees of applications of the PM practices identified. These provide the descriptive statistics for the influence of the purpose and structure of the innovative project on the level of use of the PM practices highlighted. In addition, the cross-tabulations provide information about whether there is any correlation between either the structures or the purposes of the innovative projects and the level of application of PM practices (George & Mallery, 2003; Hinton et al., 2004). The descriptive statistics are displayed in Table 5.7 below, and the correlations are presented in Tables 5.8 and 5.9.

However, these cross-tabulations would not indicate whether these two contextual variables would have an effect or not on the levels of employment of PM practices (George & Mallery, 2003; Hinton et al., 2004). Therefore, Independent-Samples *t* Tests were performed to examine whether the structure and purpose of the innovative projects influence the level of employment of the PM practices highlighted. This is because this test is undertaken when the samples are unrelated, with different participants in each sample, such as those involved in basic research and applied research. Essentially, the *t* test compares two results. The first comparison is the difference between the Mean of the two samples; the second is an estimate of what it would expect the difference in the Means to be when the null hypothesis is true.

In the survey, the university scientists were asked to point out what was the structure of the innovative project (i.e. individual and collaborative) that they referred to. Also, they were asked to indicate whether the projects were basic, applied or developmental research projects (i.e. the purpose of the innovative projects). However, as stated in section 5.1, the number of the responses to 'developmental research' was too small to make a conclusion. This work focuses on the projects categorised into basic and applied research. It was found that, the university scientists involved in either basic research or applied research projects were independent; the respondents involved in either individual or collaborative innovative projects were unrelated as well.

5.3.1. Distributions of the Levels of employment of Project Management Practices regarding the Structure and Purpose of Innovative Projects

The distributions of the levels of employment of PM practices by the university scientists involved in innovative projects with different structures and purposes, are summarised into a two-by-two matrix (see Table 5.7), i.e. the respondents are divided into four groups. In terms of the numbers of the respondents, the sizes of these four groups were ordered as follows: individual basic research (48.3%), individual applied research (23.81%), collaborative applied research (14.97%), and collaborative basic research (12.93%).

Comparing the two rows in the matrix, the correlation between the purposes of innovative project and the level of employment of the PM practices can be observed. The purposes of the innovative projects appear to correlate with the level of use of DPM and RPM rather than DPO, as the distributions of the respondents to the level of use of the former two practices are dissimilar in the two rows, but regarding the latter practice it is similar. For instance, in terms of the level of employment of DPM, most of the responses were to the 'Medium extent' in the basic research category, but to the 'High extent' in the applied research group. Moreover, taking the two columns into account, they revealed that the structures of innovative project appear not to correlate with the use of PM practices because the distributions of the levels of employment of the PM practices identified are similar.

Furthermore, these observations have been placed into the cross-tabulation analyses, so that the researcher can understand the correlations between the purpose and structure of the innovative projects and the levels of the use of the PM practices highlighted. The findings about these analyses are presented in Section 5.3.2 below.

Table 5.7: Matrix for Descriptive Statistics in terms of the Structures and Purposes of the Innovative Project

Purposes of innovative projects		Structures of the innovative projects: Individual						Collaborative					
Basic research		n = 71	71/147*100% = 48.30%					n = 19	19/147*100% = 12.93%				
		Extent of the use of DPO		Extent of the use of DPM		Extent of the use of RPM		Extent of the use of DPO		Extent of the use of DPM		Extent of the use of RPM	
		F.	P[a]	F	P	F	P	F	P	F	P	F	P
	Not at all	2	2.8	5	7.0	2	2.8	0	0	2	10.5	0	0
	To low extent	15	21.1	23	32.4	8	11.3	3	15.8	6	31.6	1	5.3
	To medium extent	22	22.8	23	32.4	19	26.8	10	52.6	8	42.1	6	31.6
	To high extent	22	22.8	18	25.4	31	43.7	6	31.6	3	15.8	7	36.8
	To the highest extent	10	14.1	2	2.8	11	15.5	0	0	0	0	5	26.3
Applied research		n = 35	35/147*100% = 23.81%					n = 22	22/147*100% = 14.97%				
		Extent of the use of DPO		Extent of the use of DPM		Extent of the use of RPM		Extent of the use of DPO		Extent of the use of DPM		Extent of the use of RPM	
		F	P	F	P	F	P	F	P	F	P	F	P
	Not at all	1	2.9	2	5.7	0	0	0	0	0	0	0	0
	To low extent	4	11.4	5	14.3	3	8.6	0	0	3	13.6	0	0
	To medium extent	12	34.3	14	40.0	6	17.1	11	50.0	9	40.9	4	18.2
	To high extent	12	34.3	11	31.4	14	40.0	9	40.9	9	40.9	10	45.5
	To the highest extent	6	14.1	3	8.6	12	34.3	2	9.1	1	4.5	8	36.4

F=Frequency; P=Percentage (%)

[a] % within the purposes of innovative projects

5.3.2. Cross-Tabulations

Cross-tabulations – purposes of innovative projects

Table 5.8 displays the cross-tabulation analysis of whether the purpose, i.e. basic research and applied research, of the innovative projects is associated with the levels of applications of DPO, DPM and RPM. Overall, the purpose is more related to the level of applications of DPM and RPM rather than the application of DPO.

Table 5.8: The Purposes of the Innovative Projects * the Levels of Employment of PM Practices Cross-Tabulation

			Extent of use of DPO					Total
			Not at all	To low extent	To medium extent	To high extent	To the highest extent	
The purposes of innovative projects	Basic research	Count	2	18	32	28	10	90
		% within the purpose of project	2.2%	20.0%	35.6%	31.1%	11.1%	100%
	Applied research	Count	1	4	23	21	8	57
		% within the purpose of project	1.8%	7.0%	40.4%	36.8%	14%	100%
	Total	Count	3	22	55	49	18	147
		% within the purpose of project	2.0%	15.0%	37.4%	33.3%	12.2%	100%
$\chi^2 = 4.770$, df = 4, p = .312								
			Extent of use of DPM					Total
			Not at all	To low extent	To medium extent	To high extent	To the highest extent	
The purposes of innovative projects	Basic research	Count	7	29	31	21	2	90
		% within the purpose of project	7.8%	32.2%	34.4%	23.3%	2.2%	100%
	Applied research	Count	2	8	23	20	4	57
		% within the purpose of project	3.5%	14%	40.4%	35.1%	7.0%	100%
	Total	Count	9	37	54	41	6	147
		% within the purpose of project	6.1%	25.2%	36.7%	27.9%	4.1%	100%
$\chi^2 = 9.651$, df = 4, $p < 0.05$								
			Extent of use of RPM					Total
			Not at all	To low extent	To medium extent	To high extent	To the highest extent	
The purposes of innovative projects	Basic research	Count	2	9	25	38	16	90
		% within the purpose of project	2.2%	7.3%	21.4%	38%	17.8%	100%
	Applied research	Count	0	3	10	24	20	57
		% within the purpose of project	0%	5.3%	17.5%	42.1%	35.1%	100%
	Total	Count	2	12	35	62	36	147
		% within the purpose of project	1.4%	8.2%	23.8%	42.2%	24.5%	100%
$\chi^2 = 8.031$, df = 4, $p < 0.1$								

In terms of the degree of employment of DPO, the observations, based on the matrix, are supported, as the value of chi-square is small and insignificant ($\chi^2 = 4.770$, df = 4, p = .312). That is, there was no difference in the levels of applications of DPO by the university scientists, when they were undertaking basic research or applied research.

The levels of application of DPM by university scientists was associated with the purposes of the innovative project, based on the value of chi-squared which is 9.651, being significant at the 5% level ($\chi^2 = 9.651$, df = 4, $p<0.05$). In addition, the data indicated that the level of the use of DPM in basic research projects was lower than that in applied research projects. This assessment is based on the following observations. Regarding the levels of use of DPM, the percentage of the university scientists undertaking basic research who replied to 'Not at all' and 'Low extent' were higher than those who were carrying out applied research projects. However, in terms of the responses to 'Medium extent', 'High extent' and 'the Highest extent', the above relationship between these percentages was reversed. That is to say, the university scientists were less likely to retain the defined project milestones as constants during project life cycle when they were undertaking basic research, than during applied research.

The degree of application of RPM by university scientists was associated with the purposes of the innovative project, based on the value of chi-square which is 8.031, being significant at the 10% level ($\chi^2 = 8.031$, df = 4, $p<0.1$). This shows that the distributions of the levels of applications of RPM by the university scientists in basic research and applied research projects were different. This is based on the following observations. Concerning the levels of employment of RPM by university scientists, the percentage figures for their replies to 'Medium extent', 'Low extent' and 'Not at all' when they were undertaking basic research were higher than when they were conducting applied research. However, a reverse tendency was observed when their replies went to 'the Highest extent', i.e. the level of the percentage of the responses to 'the Highest extent' in the basic research categories is much lower, than that for applied research. The percentages of their responses to 'High Extent' were similar when they were undertaking basic and applied research.

In sum, the purposes of the innovative project were more associated with the applications of DPM and RPM rather than DPO when the university scientists were managing innovative projects.

Cross-tabulation – structures of the innovative projects

Table 5.9 demonstrates the cross-tabulation analysis of whether the structures (i.e. individual vs. collaborative) of the innovative projects were associated with the level of employment of the PM practices by the university scientists. Based on Table 5.9, the structures only correlated with the level of use of DPO, and not with the other PM practices.

Table 5.9: The Structures of the Innovative Project * the Levels of Employment of PM Practices Cross-Tabulation

			Extent of the use of DPO					Total
			Not at all	To low extent	To medium extent	To high extent	To the highest extent	
The structures of innovative project	Individual	Count	3	19	34	34	16	106
		% within the structures of project	2.8%	17.9%	32.1%	32.1%	15.1%	100%
	Collaborative	Count	0	3	21	15	2	41
		% within the structures of project	0%	6.1%	15.3%	36.6%	4.9%	100%
	Total	Count	3	22	55	49	18	147
		% within the structures of project	2.0%	15.0%	37.4%	33.3%	12.2%	100%
$\chi^2 = 8.980$, df = 4, $p < 0.1$								

			Extent of the use of DPM					Total
			Not at all	To low extent	To medium extent	To high extent	To the highest extent	
The structures of innovative project	Individual	Count	7	28	37	29	5	106
		% within the structures of project	6.6%	26.4%	34.9%	27.4%	4.7%	100%
	Collaborative	Count	2	9	17	12	1	41
		% within the structures of project	4.9%	22.0%	41.5%	29.3%	2.4%	100%
	Total	Count	9	37	54	41	6	147
		% within the structures of project	6.1%	25.2%	36.7%	27.9%	4.1%	100%
$\chi^2 = 1.138$, df = 4, $p = .888$								

			Extent of the use of RPM					Total
			Not at all	To low extent	To medium extent	To high extent	To the highest extent	
The structures of innovative project	Individual	Count	2	11	25	45	23	106
		% within the structures of project	1.9%	10.4%	23.6%	42.5%	21.7%	100%
	Collaborative	Count	0	1	10	17	13	41
		% within the structures of project	0%	2.4%	24.4%	41.5%	31.7%	100%
	Total	Count	2	12	35	62	36	147
		% within the structures of project	1.4%	8.2%	23.8%	42.2%	24.5%	100%
$\chi^2 = 4.280$, df = 4, $p = .369$								

With respect to the level of employment of DPO, it appears to be influenced by the structures of the innovative projects, based on the value of chi-squared which is 8.980, being significant at the 10% level (χ^2 = 8.980, df = 4, p<0.1). This finding shows that the distributions of the levels of application of DPO in individual and collaborative innovative projects were different. This is based on the following facts. Firstly, concerning the levels of use of DPO by the university scientists, the percentage of the responses of those undertaking individual innovative projects to 'Not at all', 'Low extent', Medium extent', and 'the Highest extent', were much higher than those who were conducting collaborative projects. However, the percentage of the replies made by the university scientists in the individual project category to the 'High extent' level was slightly lower than that of those carrying out collaborative projects.

Regarding the application of the other PM practices, the structures of the innovative projects did not appear to be associated with the levels of employment of DPM and RPM because the values of chi-square are small and insignificant (i.e. χ^2 = 1.138, df = 4, p = .888 and χ^2 = 4.280, df = 4, p = .369, respectively).

Thus, is posited that the structures of the innovative projects are only associated with the levels of employment of DPO by university scientists, when they are managing them. In other words, the structure of innovative projects is more likely to influence the level of employment of DPO rather than DPM and RPM by university scientists, in managing the innovative projects.

Based on the two cross-tabulation examinations, it can be seen that the levels of employment of DPM and RPM by the university scientists were associated with the purposes (i.e. basic research vs. applied research) of the innovative projects. Moreover, the structures (i.e. individual vs. collaborative) of the innovative projects were only associated with the degree of application of DPO. However, how the structures and purposes of innovative project affect the levels of employment of PM practices has not yet been determined; independent-sample *t* tests will be employed to test these effects.

5.3.3. Independent-Samples t Test

Independent-sample t test – the purposes of the innovative projects

An independent-samples *t* test was performed in order to investigate whether the purposes of the innovative project influenced the level of use of PM practices by the university scientists. In accordance with the findings from the exploratory research phase and cross-tabulation examination, it is posited that the degree of employment of the PM practices highlighted for basic research is different from when carrying out applied research. Thus, the hypothesis to be tested for the prediction is that:

> *$H1_1$: the Means of the levels of the applications of the three project management practices by university scientists in basic research projects are different to those in applied research projects.*

Furthermore, in order to test if $H1_1$ would be true, a null hypothesis ($H1_0$) was formulated:

> *$H1_0$: there is no difference in the Means of the levels of the applications of the three project management practices highlighted by university scientists, regarding basic research and applied research projects.*

Table 5.10 below presents the results of the independent-samples *t* test on the comparisons of the Means of the levels of the applications of the PM practices highlighted in basic research and applied research projects.

Table 5.10: Results of the Independent-Samples *t* Test on the Employment of PM Practices Being Grouped by the Purposes of the Innovative Projects

	Levene's Test		t-test for Equality of Means			
	F value	Sig.	Means (SD)		Mean Difference	t-value (df)
			Basic research (n = 90)	Applied research (n = 57)		
Level of the employment of …						
DPO	.806	.371	3.2889 (.98579)	3.5439 (.88782)	-.25497	-.1.587 (145)
DPM	.301	.584	2.8000 (.96221)	3.2807 (.92107)	-.48070	-3.0^{**} (145)
RPM	2.368	.125	3.6333 (.96512)	4.0702 (.86313)	-.43684	-2.784^{**} (145)

Leven's Test stands for Levene's Test for Equality of Variances
$^{*}p<0.1$; $^{**}p<0.05$

Levene's test shows the data from the two groups with equal variances, as all of the F values in the cases are insignificant, indicating that the variances are not significantly different; this study accepts the equal variances assumption.

As can be seen in Table 5.10, the null hypothesis $H1_0$ is partially accepted, as the differences in the levels of employment of DPO in basic research and applied research projects are insignificant, but the usage of the other PM practices is significantly different. This confirms the findings of the cross-tabulation examinations. That is, this shows that there is no difference between the levels of employment of DPO in basic research and applied research projects. In other words, the purposes of the innovative projects do not influence their level of use of DPO by university scientists. This is consistent with the qualitative result obtained in the exploratory research phase, in which most of the university scientists viewed DPO as guidelines for keeping innovative projects on the planned tracks. However, promising and surprising results of basic research may attract them to other directions (e.g. Terziovski & Morgan, 2006). This indicates that university scientists may not seriously emphasise the established project objectives when they are undertaking basic research projects.

The *t* tests also reveal that the degrees of employment of DPM and RPM by university scientists in basic research and applied research projects are significantly different. Moreover, these levels of usage in basic research projects are lower than in applied research projects, confirming the findings of the cross-tabulation examinations and the exploratory phase. This indicates that university scientists do engage in DPM when undertaking basic research; however, they are more likely to redefine DPM during the project life cycle, than when they are involved in applied research. In addition, they are more likely to monitor project progress through *regular* and *irregular* research meetings, when they are undertaking basic research projects. This is based on the interview statements presented in Chapter Four. Moreover, in this set of data, it can be seen that applied research projects are more likely to be collaborative projects (Table 5.7), leading to more emphasis being placed on *regular* progress monitoring by university scientists.

Independent-sample t test – the structures of the innovative projects

An independent-samples *t* test was conducted to examine whether the structures of innovative project would influence the university scientists in utilizing the PM practices highlighted. Based on the findings of the exploratory research stage and the cross-tabulation examination, this researcher makes the assumption that the level of employment of the PM practices by the university scientists, when they are undertaking individual innovative projects, is different to when they are carrying out collaborative innovative projects. Thus, the hypothesis to be tested for the assumption is that:

> *$H2_1$: the Means of the levels of the applications of the three project management practices by university scientists in individual research projects are different to those in collaborative research projects.*

Furthermore, in order to test if $H2_1$ is true, a null hypothesis ($H2_0$) is formulated:

> *$H2_0$: there is no difference in the Means of the levels of the applications of the three project management practices highlighted by university scientists, regarding individual research and collaborative research projects.*

Table 5.11 below presents the results of the independent-samples *t* test on the comparisons of the Means of the extent of the applications of the PM practices identified, in individual and collaborative innovative projects, by university scientists.

Table 5.11: Results of the Independent-Samples *t* Test on the Employment of PM Practices Being Grouped by the Structures of the Innovative Projects

	Levene's Test		t-test for Equality of Means			
	F	Sig.	Means (SD)		MD	t-value (df)
			Individual project (n = 106)	Collaborative project (n = 41)		
Extent of the employment of …						
DPO	9.194	.003	3.3868 (1.03805)	3.3902 (.70278)	-.00345	-.023 (106.973)
DPM	.863	.355	2.9717 (.99960)	3.0244 (.90796)	-.05269	-.294 (145)
RPM	3.002	.085	3.7170 (.98324)	4.0244 (.82121)	-.30741	-1.922^{*} (86.522)

Levene's Test stands for Levene's Test for Equality of Variances
MD stands for Mean Difference
$^{*}p<0.1$

Based on Levene's test, the F values of the cases employing DPM are insignificant, indicating the variances are not significantly different and, therefore, this study accepts the equal variances assumption to the applications of DPM. The F values in the cases of the employment of DPO and RPM are significant, implying the variances of such applications by university scientists in individual and collaborative innovative projects, are significantly different. Hence, this study does not accept the equal variance assumption, and reports the *t* value associated with the 'Equal variances not assumed'[2]on the bottom line of the SPSS output table.

As can be seen in Table 5.11, the null hypothesis $H2_0$ is partially accepted, as the levels of employment of RPM are significantly different, and the levels of uses of

[2] It has been suggested (e.g. Hinton, et al., 2004) that if Levene's test statistic is significant it is a matter of academic judgement whether the study accepts the values on the bottom line, or whether the study sees this is as a violation of the parametric test assumptions, and therefore as a justification to perform the nonparametric Mann-Whitney test instead. In accordance with this suggestion, this study performed a nonparametric Mann-Whitney test, and the results of the Tests of the applications of DPO and RPM in the cases are as same as the Independent-sample *t* testes (data not shown).

DPO and DPM are not significantly different. This is inconsistent with the findings obtained in cross-tabulations (see Table 5.5). However, this study adopts the results obtained from the *t* tests, because the *t* test is employed to examine whether the structure and purpose of the innovative projects have an effect on the two samples (George & Mallery, 2003; Hinton et al., 2004). That is to say, the structures of innovative project only influence the level of employment of RPM rather than the other two PM practices.

There was no difference between the levels of employment of DPO and DPM, that is, there was no effect of the structures of the innovative projects on the level of use of DPO and DPM. However, the structures of the innovative projects significantly influenced the level of employment of RPM in managing innovative projects. In addition, the level of application of RPM was increased when they were undertaking collaborative innovative projects, based on the negative value of the Mean difference (see Table 5.11). These findings do not confirm those gained from the exploratory research. In the exploratory research, most university scientists asserted that the structures of the projects influenced them in applying DPO and DPM, and the levels of applications of these two PM practices in collaborative innovative projects were higher than in individual ones. Furthermore, the level of application of RPM appeared not to be influenced by the structure. However, the *t* test showed that its levels of usage, when comparing individual and collaborative innovative projects, were significantly different.

The findings regarding the applications of DPO and DPM could be explained as follow. Most university scientists still have the mindsets of seeking scientific significance when they are carrying out innovative projects, based on the interview statements gathered for this study and relevant literature (e.g. Cohen et al., 1999a; Cohen et al., 1999b; Terziovski & Morgan, 2006). In terms of the employment of RPM, the structures of the innovative projects influence university scientists in employing this practice, and the degree of its use in collaborative projects is higher than in individual cases. One possible reason for this finding is that university scientists are likely to be required to *regularly* monitor the project progress of collaborative projects by other stakeholders, such as industrial collaborators and funding bodies. However, regarding the undertaking of individual projects, they may check project progress through informal discussions or communications, from time to time, in addition to monitoring project progress through *regular* research meetings. This indicates that no matter what the structure of innovative project, university scientists emphasise the importance of monitoring project progress. However, *regular* progress monitoring is more likely to be employed in collaborative projects and this is more likely attributed to the requests made by the outside stakeholders. Nevertheless, *regular* progress monitoring is likely to become less important to monitor progress of individual projects, as the university scientists can informally check on project progress from time to time.

Nevertheless, the finding discussed above is inconsistent with that observed in the exploratory phase, in which the structures of the innovative projects appeared to influence the level of employment of the PM practices highlighted. However, in the explanatory phase, the influence is only on the level of use of RPM. The inconsistency could be attributed to the difference in respondents' research experience, involved in the two phases. Most of the respondents involved in the interviews have had abundant experience in undertaking UICs, and they would clearly state what really happened, when carrying out individual and collaborative projects. However, the respondents in the explanatory phase were mixed, i.e. some of them have not had any experienced in conducting UICs, and some of them may have had little experience in undertaking them, although they categorised their projects as collaborative.

In sum, based on the results of the cross-tabulations and the Independent-Samples *t* Tests, the purposes of innovative projects significantly influences the level of employment of DPM and RPM. Moreover, the levels of usage of DPM and RPM in applied research projects are higher than in basic research. Regarding the structure of the innovative project, this characteristic significantly influences university scientists in employing RPM, but has no effect on the level of the use of DPO and DPM. Figure 5.3 depicts these findings.

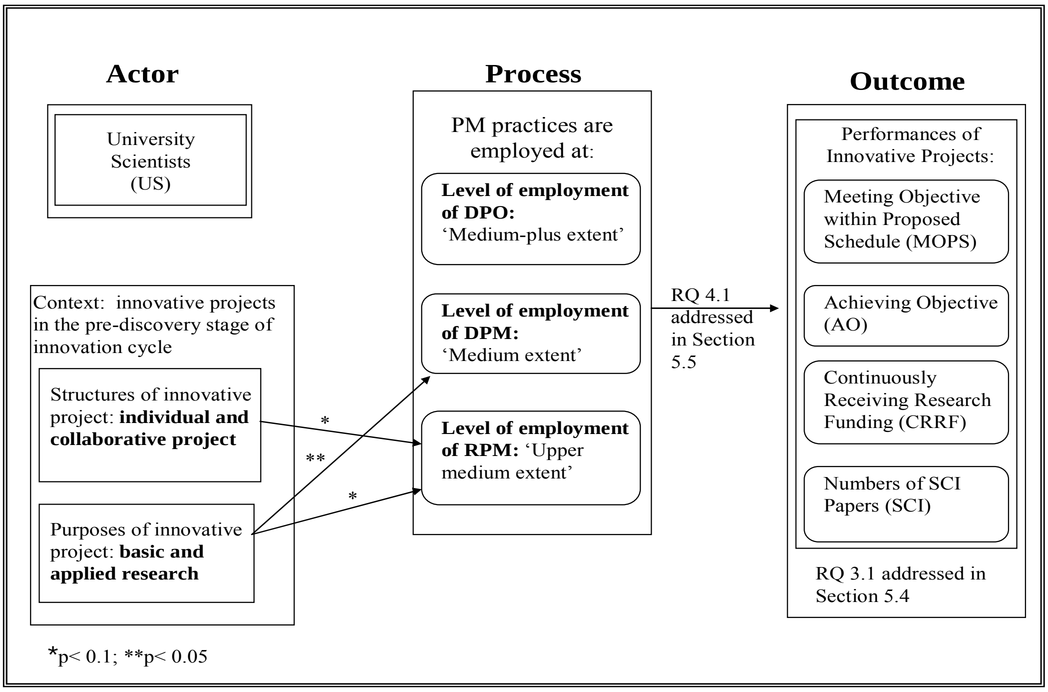

Figure 5.3: Findings of the Influences of the Purpose and Structure of the Innovative Projects on the Levels of Employment of the PM Practice Highlighted

5.4. Outcome (Level of Achievement of Performance Criteria)

Having presented the degree of usage of the PM practices highlighted by university scientists during the innovative projects, this section shows to what extent the projects reach the performance criteria identified in the exploratory research (see Table 4.11). Four defined criteria were employed to determine the performance of innovative projects in the explanatory research; these were MOPS (Meeting Objective within Proposed Schedule), AO (Achieving Objective), CRRF (Continuously Receiving Research Funding) and SCI (Numbers of SCI Papers published). Thus, the revised research question 3.1 was formulated (being illustrated in Figure 5.1):

- RQ 3.1: to what extent do innovative projects undertaken by university scientists achieve the performance criteria of the projects, in terms of MOPS, AO, CRRF and SCI (Outcome)?

In the survey, the university scientists were asked to indicate to what extent the projects being undertaken by them met the objectives within the proposed schedules, achieved the pre-stated project objectives, and received follow-up research funding. In addition, in terms of SCI, they were asked to identify a point on a scale, which referred to the numbers of SCI papers that had been published or accepted in a certain period, i.e. 2002-2004. In terms of the SCI scale, numbers of SCI papers that had been published or accepted was divided into five categories[3]. The rationale behind this was to maintain the consistency with the other scales of measurements. The adoption of the period 2002-2004 was based the view that publications for projects are concurrent with their execution, as well as being produced after competition. For this reason, the period 2002-2004 was chosen for the SCI data, in accordance with Herbertz & Muller-Hill' (1995) who argued that there could be a three year time lag (e.g. delays in the writing up process, in reviewing process). The survey was carried out in the middle of 2005; therefore, three years starting in 2002 were used for this data.

5.4.1. Level of Achievement of Meeting Objective within Proposed Schedule (MOPS)

This study has highlighted MOPS as one of the criteria for determining the performance of innovative projects being carried out by university scientists. In the survey, they were asked to indicate to what extent the projects being undertaken by them achieved project objectives within the proposed schedules (MOPS) and in accordance with the research proposals. Table 5.12 displays the responses to the level of achievement of MOPS.

Table 5.12: The Responses to the Level of Achievement of MOPS

Variable – MOPS	Measurements[1]	
	Please indicate to what extent the innovative projects being executed by you met the project objectives within the proposed schedules according to research proposals.	
N	147	
Mean	3.59	
Mode	4	
SD	.935	
Response to…	Frequency	Percentage
Not at all	4	1.4
Low extent	14	9.5
Medium extent	41	27.9
High extent	68	46.3
The highest extent	20	13.6

[1] Scale: 1 = Not at all, 5 = the highest extent

Based on Table 5.12, 46.3% of the respondents indicated that the projects reached the defined project objective within the agreed time-span at the 'High extent' level. 27.9% of the respondents indicated that the degree of projects' achievement of MOPS was at the 'Medium extent' level and 13.6% of the respondents stated that they reached MOPS at the 'the Highest extent' level. The rest of the respondents were less likely to achieve the pre-stated project objectives within the proposed schedules, with those

[3] The scale is designed as follow: 1 = 1-3, 2 = 4-6, 3 = 7-9, 4 = 10-12, 5 = 13 and above, SCI papers have been published or accepted; 9 = non-applicable (Please indicate the reason____).

who indicated at the ‘Low extent’ level and ‘Not at all’, sharing 9.5% and 1.4% of the respondents, respectively. In addition, it can be seen that the greatest numbers of projects achieved MOPS at the ‘High extent’ level, i.e. the value of Mode was 4, and on average the projects met MOPS at a level higher than the ‘Medium extent’ level, (the value of Mean was 3.59). Therefore, the level of achievement of the innovative projects achieving MOPS is defined as at the ‘Upper medium extent’ level.

5.4.2. Level of Achievement of Achieving Objective (AO)

The second criterion employed to measure the performance of the innovative projects in the survey was AO. In the explanatory research phase the university scientists were asked to indicate, to what extent the innovative projects being undertaken by them, achieved the proposed project objectives in accordance with the research proposals. Table 5.13 displays the projects’ achievement of AO.

Table 5.13: The Responses to the Level of Achievement of AO

Variable – AO	Measurements[1]	
	Please indicate to what extent the innovative projects being executed by you met the project objectives in accordance with research proposals.	
N	147	
Mean	3.86	
Mode	4	
SD	.922	
Response to…	Frequency	Percentage
Not at all	3	2.0
Low extent	8	5.4
Medium extent	32	21.8
High extent	68	46.3
The highest extent	36	24.5

[1] Scale: 1 = Not at all, 5 = the highest extent

Based on Table 5.13, the distribution of the responses to AO was similar to the distribution of the responses to MOPS; however, there were more respondents who expressed that their projects achieved AO to the ‘the Highest extent’ level. Most respondents stated that their projects met AO at the ‘High extent’ level, i.e. the value of the Mode was 4, and on average indicated that the projects met AO at a level, which was close to the ‘High extent’ level (the value of Mean was 3.86). Consequently, the level of achievement of the innovative projects meeting AO is defined as at the ‘Upper medium extent’ level.

Both of the levels of achievement of MOPS and AO are defined as the ‘Upper medium extent’ level, as their Mean values were 3.59 and 3.86, respectively. However, the level of achieving AO is higher than that of achieving MOPS, as the paired sample *t* test result is: $t(146)=4.321$; $p<0.001$. This indicates that most of the innovative projects completed the proposed project objectives behind the agreed time schedule, consistent with the prior reports that pointed out most of them ran behind the planned schedules.

5.4.3. Level of Achievement of Continuously Receiving Research Funding (CRRF)

In the exploratory research, CRRF was highlighted as one of the criteria for assessing the performance of the innovative projects, being undertaken by university scientists. In the survey, the university scientists were asked to indicate to what extent the innovative projects being conducting by them continuously received follow-up research funding. Table 5.14 presents the distribution of the responses to the question.

Table 5.14: The Responses to the Level of Achievement of CRRF

Variable – CRRF	Measurements[1]	
	Please indicate to what extent the innovative projects being executed by you continuously received follow-up research funding.	
N	147	
Mean	4.06	
Mode	5	
SD	1.160	
Response to…	Frequency	Percentage
Not at all	7	4.8
Low extent	9	6.1
Medium extent	25	17.0
High extent	33	22.4
The highest extent	73	49.7

[1] Scale: 1 = Not at all, 5 = the highest extent

Based on Table 5.14, 49.7% of the respondents indicated that the projects being undertaken by them always received follow-up research funding, i.e. at the 'the Highest extent' level (the value of Mode was 5). On average, the projects achieved CRRF at the 'High extent' level (the value of Mean was 4.06). Indeed, 72.1% of the respondents expressed that their projects usually received follow-up research funding (i.e. at the 'High extent' and the 'the Highest extent' levels). Therefore, the level of achievement the innovative projects that university scientists were involved in is defined as at the 'High extent'.

5.4.4. Level of Achievement of Numbers of SCI Papers Published (SCI)

The last criterion for measuring the performance of innovative projects being undertaken by university scientists identified was SCI. This criterion is not only related to the university scientists, but also associated with industrial firms in the biotechnology sector. From the industrial managers' point of view, SCI could show the capabilities of an individual or organisation performing innovative projects well, and then producing good quality outcomes (Boffo et al., 1999). Moreover, publishing the outcomes of innovative projects in SCI journals usually indicates the results have drawn the attention of the scientific community, and the quality of the findings has reached a level where dissemination is appropriate (Herbertz & Muller-Hill, 1995; Narin et al., 1997). Futhermore, from the university scientists' standpoint, SCI is also associated with their professional status and promotion in their academic career, as mentioned in Chapter Four.

In the survey, the university scientists were asked to tick an appropriate box to indicate how many SCI papers they had had published or accepted in a three year period, i.e. 2002 to 2004. The rationale behind the selection of this period has been explained previously. Table 5.15 shows the distribution of the responses to the performance criterion – SCI.

Table 5.15: The Responses to the Level of Achievement of SCI

Variable – Numbers of SCI Paper	Measurements[1]	
	Please indicate how many SCI papers you have published or been accepted during the period from 2002 to 2004.	
N	143	
Missing[2]	4 (2.7%)	
Mean	2.09	
Mode	1	
SD	1.321	
Response to…	Frequency	Valid Percentage (Missing data is excluded)
1 = 1-3 SCI papers	65	45.5
2 = 4-6 SCI papers	37	25.9
3 = 7-9 SCI papers	20	14.0
4 = 10-12 SCI papers	5	3.5
5 = 13 and above SCI papers	16	11.2

[1] Scale: 1 = 1-3, 2 = 4-6, 3 = 7-10, 4 = 11-13, 5 = 14 and above, 9 = non-applicable (Please indicate the reason____) SCI papers have been published or accepted

[2] Non-applicable treated as missing data

As can be seen in Table 5.15, 2.7% of the respondents replied 'non-applicable', as they stated that in the past few years they undertook UICs (i.e. commissioned projects), and the publications of the results of these projects were restricted by their industrial collaborators, because of the issues related to the protection of intellectual property rights. In addition, in general, there was a reverse relationship between the numbers of SCI papers and the numbers of respondents; however, the numbers of the respondents in category 5 was higher than that in category 4 and almost equal to the numbers of the respondents in the category 3. Owing to the lack of sufficient information, this study can not explain this phenomenon.

Based on Table 5.15, in the period of 2002 – 2004, 45.5% of the respondents published one to three SCI papers. 25.9% of the respondents indicated that the numbers of publications were four to six SCI papers. The respondents in categories 3 and 5 were almost equal, with 14% and 11.2% shares, respectively, showing that the numbers of their SCI publications was seven to nine, and more than twelve, respectively. 3.8% of the respondents were in category 4, publishing ten to twelve SCI papers. Most of the respondents published one, two or three SCI paper(s), i.e. the value of Mode was 1, and on average they published four to six SCI papers, with a Mean value of 2.09.

5.4.5. Correlations between the level of achievement of the Performance Criteria

Drawing upon findings in last three sections, on average, the levels of achievement of the performance of the innovative projects being undertaken by university scientists in terms of MOPS, AO and CRRF have been determined to be at the 'Upper Medium extent', 'Upper medium extent' and 'High extent' levels, respectively. In addition, most of the respondents published four to six SCI papers during the period 2002 – 2004. This section sets out to determine the relationship between the levels of the achievement of these performance criteria by Pearson Correlation. Table 5.16 presents the results of Pearson Correlation examinations.

Table 5.16: Correlations between the Levels of Achievement of the Performance Criteria

Variable	MOPS	AO	CRRF	SCI
MOPS	1			
AO	.662**	1		
CRRF	.226**	.143	1	
SCI	-.026	-.013	.253**	1

N = 147 (N=143 in SCI)
**$p<0.05$

Based on Table 5.16, it can be seen that apart from SCI, the variable related to the efficiency of the innovative projects, MOPS, is significantly correlated with the other variables, i.e. AO and CRRF. With respect to AO, it is only significantly correlated with MOPS, rather than CRRF and SCI. Regarding CRRF, it is only significantly correlated with MOPS and SCI, rather than AO. In terms of SCI, it is only significantly correlated with CRRF, but is insignificantly correlated with the other two criteria. These correlations indicate that meeting project objectives within the agreed time-span, rather than just meeting objectives, is more likely to contribute to receiving follow-up research funding, ultimately contributing to the publication of SCI papers. This is because MOPS, rather than AO, significantly correlates with CRRF, and CRRF is significantly associated with SCI. This will be considered in the discussion chapter. Moreover, these findings echo the prior findings that the university scientists have acknowledged that there was more pressure on them than ever before, regarding the efficiency and accountability of projects (e.g. Cohen et al., 1999a; Cohen et al., 1999b).

In sum, the levels of the innovative projects' achievements in terms of the four performance criteria highlighted have determined. The levels of achievements of MOPS, AO, CRRF, and SCI were 'Upper medium extent', 'Upper medium extent', 'High extent', and 'Four to six SCI papers', respectively. This has addressed research question 3.1. Figure 5.4 illustrates the research questions that have been addressed thus far.

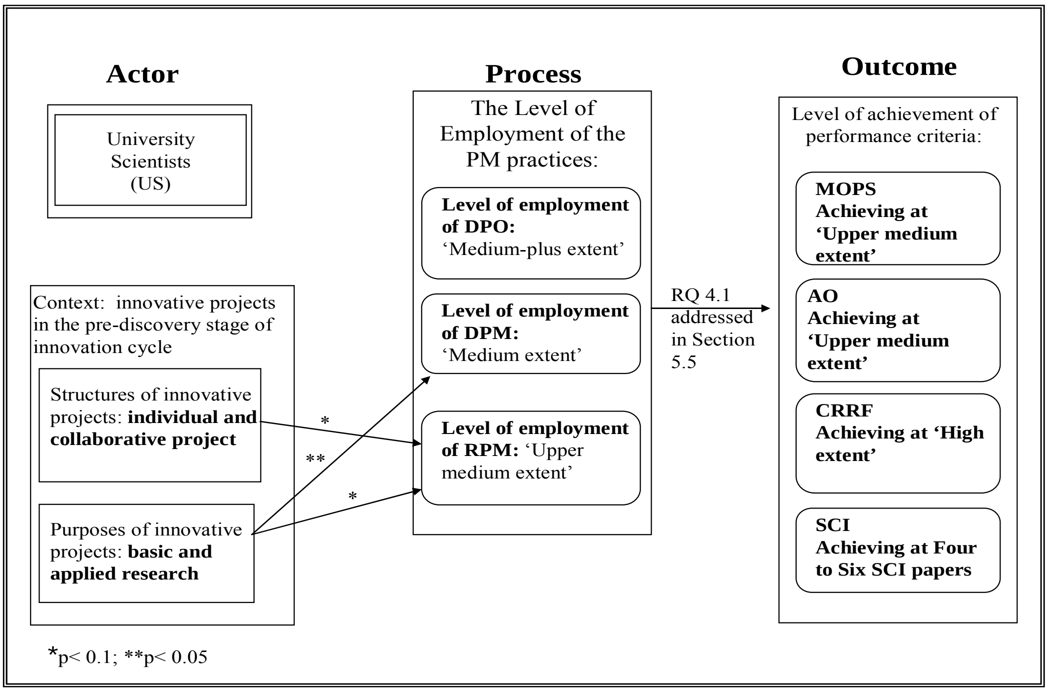

Figure 5.4: Level of Achievement of the Performance Measurements Identified

5.5. Impacts of Project Management Practices on the Performance of Innovative Projects

It can be seen in Figure 5.4, that RQ 4.1 has not been addressed. This section is concerned with providing an overview of the analysis of how the PM practices highlighted impact on the performance of the innovative projects, in terms of the four criteria identified. The aim is to address RQ 4.1 formulated as:

- RQ 4.1: what impacts does the employment of DPO, DPM and RPM (Process) have on the performance of innovative projects in terms of MOPS, AO, CRRF and SCI (Outcome)?

The findings in the exploratory research have already indicated that the employment of three PM practices – DPO, DPM and RPM – appear to influence the performance of innovative projects being undertaken by university scientists, in terms of four criteria, i.e. MOPS, AO and CRRF, and SCI. Hence, in order to shed more light on these relationships, correlations, and 'enter' and 'stepwise' regressions on all the variables were performed. The reason for employing stepwise regression is to attempt to find out the most appropriate combination of applications of the individual PM practices that can be used to predict the performance of the projects. Table 5.17 shows the correlations between the variables of the levels of employment of PM practices and the levels of achievement of the performance criteria for the innovative projects.

Table 5.17: Correlations between the Variables of Levels of Employment of the PM Practices and Achievement of the Performance Criteria

Variable	DPO	DPM	RPM	MOPS	AO	CRRF	SCI
DPO	1						
DPM	.707***	1					
RPM	.494***	.710***	1				
MOPS	.481**	.634**	.587**	1			
AO	.414**	.495**	.500**	.662**	1		
CRRF	.133	.140	.192**	.226**	.143	1	
SCI	-.040	-.015	-.024	-.026	-.013	.253**	1

N = 147 (N =143 in SCI)
** p<0.05; *** p<0.001

Based on Table 5.17, only two performance criteria, MOPS and AO, are significantly and positively correlated with all the PM practices highlighted. CRRF is only positively and significantly correlated with RPM, and, SCI is insignificantly correlated with any of the usage of PM practices. The results of the correlation examinations have raised three implications. Firstly, the impacts of the employment of the PM practices are more likely to be on the efficiency of the innovative project, as the three PM practices are significantly correlated with MOPS and AO, but only RPM is correlated with CRRF. Secondly, RPM appears to play a vital role in the employment of PM practices, as RPM is significantly correlated with the other two PM practices, and all of performance criteria, except for SCI. Finally, the influence of the employment of RPM on CRRF may be mediated by MOPS, as MOPS rather than AO significantly correlates with CRRF. The first and second implications will be addressed in this section, but the third will not be tested because it is outside the research boundaries. However, the third implication will be discussed in chapter seven, in terms of further research proposals. These correlation examinations have provided supportive information, regarding the relationships between the application of PM practices and the performance of innovative projects. However, these correlations do not explain whether the applications would have an effect on the performance of innovative projects. Therefore, regressions are performed to address this.

5.5.1. Regression – Meeting Objective within Proposed Schedule (MOPS)

Figure 5.4 illustrates that the employment of the three PM practices, i.e. DPO, DPM and RPM, have been defined as independent variables, and the four performance criteria – MOPS, AO, CRRF and SCI have been considered as dependent variables. This sub-section is to examine whether the applications of the PM practices highlighted could predict the level of achievement of MOPS by regression, in an attempt to find out the level of the influence of the employment of the PM practices on MOPS. That is to say, MOPS is chosen as the dependent variable, and the applications of the PM practices identified were as the independent variables in the regressions. Table 5.18 below presents the results of the regression of the influences of use of the PM practices on MOPS.

Table 5.18: Regressions on the Employment of the PM Practices and MOPS

Independent variables	Dependent variable – MOPS				
	Model 1	Model 2	Model 3	Model 4	Model 5
(1) DPO	.481***				
(2) DPM		.634***			
(3) RPM			.587***		
(4)[a] DPO				.070	
DPM				.398**	.439***
RPM				.276**	.275**
N	147	147	147	147	147
Method	Enter	Enter	Enter	Enter	Stepwise
R	.481	.634	.587	.665	.663
R^2	.231	.402	.344	.442	.440
Adjusted R^2	.226	.398	.340	.430	.432
F for ΔR^2	43.636***	97.531***	76.127***	$F_{(3, 143)}$=37.764***	$F_{(1, 144)}$=9.623**

Regression coefficients are standardised.
**$p < 0.05$, ***$p < 0.001$
[a] the application of the three PM practices together

Models 1-3 present the contributions of the employment of DPO, DPM and RPM to predict the performance of innovative projects being undertaken by university scientists, in terms of MOPS. Regarding the uses of the individual PM practices, the employment of DPM appears to make the most contribution to MOPS, slightly higher than the application of RPM. In addition, the least contribution to MOPS is made by the application of DPO.

Whilst the employment of the individual PM practices significantly and positively contributes to the level of achievement of MOPS, the influence of the application of the combination of the PM practices on MOPS is investigated. This is because in practice the PM practices are more likely to be employed together, based on the conclusions gained from the exploratory research phase. Models 4 and 5 are multiple regressions, in which enter and stepwise methods were employed to test whether the use of the three independent variables, together, would be a significant predictor for the level of achievement of MOPS.

It can be seen in Model 4 that the standardised coefficient of the employment of DPO is insignificant; therefore, such application is excluded by Model 5, being performed by stepwise method. This is because the predictive power of an independent variable (i.e. DPO) is not only determined by its correlation to the dependent variable, but also its correlation to other independent variables already in the model (i.e. DPM and RPM). In the case of this study, the effect of multi-collinearity is to limit the value of DPO, because of its strong relationship with DPM and RPM. It is important to avoid the conclusion that DPO is inconsequential in driving MOPS, simply because it is not included in the stepwise regression model. Model 5 demonstrates that the employment of DPM and RPM together significantly predicates the performance of innovative projects, accounting for 43.2% of the variance in the level of achievement of MOPS. Taking Models 1-5 into account, whilst all of the applications of the individual PM practices contribute to the level of achievement of MOPS, the greatest contribution to such performance is made by the application of DPM and RPM together.

In sum, the employment of the PM practices individually, and application of DPM and RPM together predict the level of achievement of MOPS for the innovative projects being undertaking by the university scientists.

5.4.2. Regression – Achieving Objective (AO)

Table 5.19 below presents the results of the regressions on the employment of the individual PM practices and the combination of the PM practices together by university scientists, and the performance of the innovative projects being carried out by them in terms of AO.

Table 5.19: Regressions on the Employment of the PM Practices and AO

Independent variables	Dependent variable – AO				
	Model 6	Model 7	Model 8	Model 9	Model 10
(1) DPO	$.414^{***}$				
(2) DPM		$.495^{***}$			
(3) RPM			$.500^{***}$		
(4)[a] DPO				.133	
DPM				.185	$.301^{**}$
RPM				$.303^{**}$	$.281^{**}$
N	147	147	147	147	147
Method	Enter	Enter	Enter	Enter	Stepwise
R	.414	.495	.500	.546	.538
R^2	.171	.245	.250	.298	.290
Adjusted R^2	.166	.240	.245	.284	.280
F for ΔR^2	29.989^{***}	46.998^{***}	48.462^{***}	$F_{(3, 143)}=20.283^{***}$	$F_{(1, 144)}=7.931^{**}$

Regression coefficients are standardised.
$^{**}p < 0.05$, $^{***}p < 0.001$
[a] the application of the three PM practices together

Similar to the findings in Models 1-5, the results for Models 6-10 demonstrate that the application of DPM and RPM together, (i.e. Model 10), appear to be the most powerful model to predict to what extent the innovative projects achieve AO. However, the prediction power of Model 10 is lower than that of Model 9 (i.e. the employment of DPO, DPM and RPM together) but only by 0.4 per cent. Nevertheless, it is acknowledged the employment of DPM and RPM together is the best model to predict the level to which the innovative projects reach AO. This is because in Model 9, the effect of multi-collinearity is to limit the value of DPO and DPM, owing to their strong relationship with RPM; as a result, the prediction power only results in the effect of the employment of RPM. In such circumstances Model 8 would substitute the prediction made by Model 9, but the prediction power of the former is lower than Model 10 by 3.5 per cent.

The regression results support the findings obtained in the exploratory research phase, in which the university scientists investigated stated that the influence of the employment of DPO on AO was lower than on the applications of DPM and RPM, and employment of RPM made the greatest contribution to the level of achievement of AO, as compared with the uses of DPO and DPM (referring Models 6-8). Taking the results of Models 5 and 10 into account, the influence of the employment of DPM and RPM together on MOPS is greater than on AO by 14 per cent. This indicates that the employment of DPM and RPM together could enhance the level of the efficiency of innovative projects being undertaking by the university scientists (i.e. MOPS).

5.4.3. Regression – Continuously Receiving Research Funding (CRRF)

This section is to show the regressions on the applications of the PM practices on CRRF. Table 5.20 below presents the results of the regressions.

Table 5.20: Regressions on the Employment of the PM Practices and CRRF

Independent variables	Dependent variable – CRRF				
	Model 11	Model 12	Model 13	Model 14	Model 15
(1) DPO	.133				
(2) DPM		.140			
(3) RPM			.192*		
(4)[a] DPO				.071	
DPM				-.042	
RPM				.187	.192*
N	147	147	147	147	147
Method	Enter	Enter	Enter	Enter	Stepwise
R	.133	.140	.192	.198	.192
R^2	.018	.020	.037	.039	.037
Adjusted R^2	.011	.013	.030	.019	.030
F for ΔR^2	2.616	2.918	5.528*	$F_{(3, 143)}$=1.948	5.582*

Regression coefficients are standardised.
*p<0.1
[a] the application of the three PM practices together

As can be seen in Table 5.20, only the employment of RPM significantly influences the performance of the innovative projects in terms of CRRF. However, the degree of such influence is very low, as the value of the standardised coefficient of this application is 0.192, and the application only accounts 3.0 per cent of the variance of the level of achievement of CRRF. In other words, the employment of RPM contributes little to the level of achievement of receiving follow-up research funding. In addition, these findings confirm those found in the exploratory research stage. The university scientists interviewed asserted that the employment of RPM positively and significantly contributed to the level of the achievement of CRRF, and the level was greater than those levels from DPO and DPM.

Considering the results obtained from Models 5, 10 and 15 together, two implications have emerged. Firstly, the employment of RPM or the employment of DPM and RPM together by university scientists is more likely to enhance the level of achievement of MOPS, than any other single or combined PM practices, and this may positively contribute to receiving follow-up research funding, owing to the positive and significant correlation between MOPS and CRRF. Secondly, the influence of the application of RPM on CRRF appears to be mediated by the performance criterion – MOPS, reinforcing the implications from the results of the Pearson correlations.

5.4.4. Regression – Numbers of SCI Papers Published (SCI)

Table 5.21 below presents the results of the regressions on the applications of the individual PM practices and the combination of the PM practices together, and the performance of the innovative projects in terms of SCI.

Table 5.21: Regressions on the Employment of the PM Practices and SCI

Independent variables	Dependent variable – SCI				
	Model 16	Model 17	Model 18	Model 19	Model 20[b]
(1) DPO	-.040				
(2) DPM		-.015			
(3) RPM			-.024		
(4)[a] DPO				-.058	
DPM				.044	
RPM				-.026	
N	147	147	147	147	
Method	Enter	Enter	Enter	Enter	Stepwise
R	.040	.015	.024	.048	
R^2	.002	.000	.001	.002	
Adjusted R^2	-.005	-.007	-.007	-.019	
F for ΔR^2	.226	.0.33	.080	.105	

Regression coefficients are standardised.

[a] the combination of variables of the applications of the three PM practices

[b] stepwise method was employed, but all independent variables were removed, as their probabilities were bigger than .100 (data not shown).

As can be seen in Table 5.21, there is no significantly predictive power of the use of PM practices to the level of achievement of SCI, i.e. the numbers of SCI papers published or accepted. These results are inconsistent with the findings obtained in the exploratory phase, in which the university scientists interviewed stated that the employment of RPM appeared to positively contribute to the numbers of publications of SCI papers. This indicates that the influence of the application of RPM on publishing SCI papers is most likely mediated by another factor(s). For instance, based on the correlation examination in this study, these two variables would be mediated by CRRF. In addition, the publication of SCI papers is more than likely to be affected by other factors, e.g. the contributions to the scientific community. This will be explored further in the discussion chapter.

In sum, based on the results of all of the Regression Models, the employment of PM practices positively and significantly contributes to the level of achievement of MOPS, AO, and CRRF, but insignificantly to SCI. Moreover, the degrees of the significant contributions in descending order are: MOPS, AO, and CRRF, respectively. Specifically, the application of DPM and RPM together appears to be the most powerful model to predict the level of achievement of MOPS and AO. However, only the employment of RPM can predict the level of achievement of CRRF. In other words, monitoring project progress *regularly* with the defined project milestones, is more likely to enhance the level of achievement of meeting the project objective within the agreed time-span, and such achievement could lead to follow-up research funding being granted. Figure 5.5 below depicts the results of the regressions, and previous findings, i.e. the findings of the explanatory research stage.

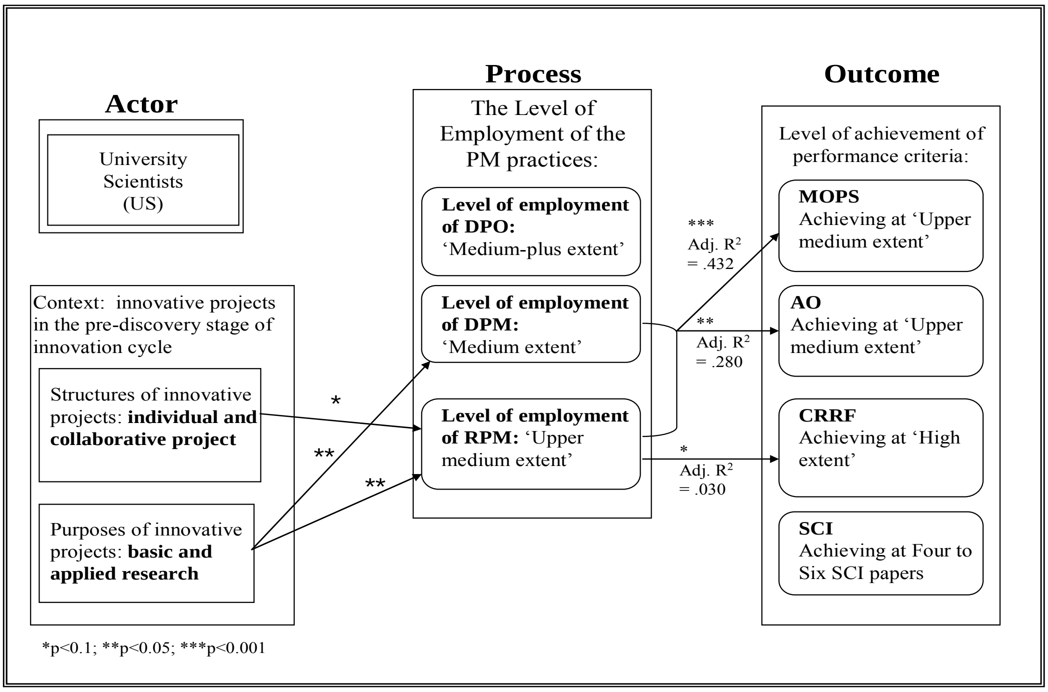

Figure 5.5: Findings in the Explanatory Phase

5.6. Chapter Summary

The findings of the explanatory research have presented the purposes (i.e. basic research vs. applied research) and structures (i.e. individual vs. collaborative) of innovative projects and how these factors influence the level of employment of the PM practices identified. Moreover, it has been found that the levels of employment of DPM and RPM are influenced by the purposes of the innovative projects, and the application of RPM, rather than DPO and DPM is influenced by the structures of innovative project.

This chapter has presented the findings of the explanatory research phase, which partially confirmed the findings in the exploratory phase. The analysis of the data for 147 university scientists confirmed that the levels of employment of the PM practices, i.e. DPO, DPM and RPM, are defined as at the 'Medium-plus extent', 'Medium extent' and 'Upper medium extent' when they are undertaking innovative projects within the research boundaries of this study.

The findings of this phase have also demonstrated the levels of achievement of the performance criteria highlighted. The levels of achievement of MOPS, AO and CRRF are defined as at the: ‘Upper medium extent’, ‘Upper medium extent’ and ‘High extent’, respectively. In addition, most of the respondents indicated they had published and been accepted four to six SCI papers in the period 2002-2004.

The effectiveness of the applications of the three PM practices on the four performance criteria were examined by regressions. Whilst the applications of the individual PM practices significantly influence the levels of achievement of MOPS and AO, the most significant influences on these two performance criteria are attributed to the employment of DPM and RPM together. Moreover, only the use of RPM contributes to the degree of achievement of CRRF. Finally, there is no application of PM practices that significantly affects the level of achievement of SCI.

Chapter Six: Summary and Discussion

The primary aim of this study was to gain a better understanding of how university scientists manage innovative projects, from the project management perspective. This was motivated by the following observations. Research has shown that UICs have been increasingly deployed as drivers of innovation across a range of sectors, such as manufacturing and biotechnology, and university scientists appear to be the predominant players. Yet high performance of such collaborations remains elusive, owing to the situation that time and cost objectives are often unmet. The use of PM practices would aid project efficiency and effectiveness, and even higher success levels (e.g. PMI, 2004). In addition, literature on how the key players, i.e. university scientists in this study, manage such UICs (i.e. collaborative projects) and even individual projects is still scarce.

The aim of this study was to fill this gap and explore how university scientists manage innovative projects. As a result, four research questions were formulated. These questions were qualitatively addressed by collecting and analysing data from nine industrial managers and twelve university scientists involved in nine biotechnology UICs. In addition, quantitative data from 147 university scientists in biotechnology related departments at universities in Taiwan was also analysed. An analysis of the interview data was used to establish a valid and reliable construct and quantitative measurements, regressions, used to test the main effect. In addition, independent-sample *t* tests were conducted for identifying the influence of the purpose and structure on the level use of PM practices. Therefore, the discussion is primarily based on the findings obtained from the explanatory phase.

This study has highlighted three PM practices – DPO (Defined Project Objective), DPM (Defined Project Milestones) and RPM (Regular Progress Monitoring) – as the variables of the employment of PM practices, and four criteria – MOPS (Meeting Objective within Proposed Schedule), AO (Achieving Objective), CRRF (Continuously Receiving Research Funding) and SCI (Numbers of SCI papers published) – as the variables of the measurements for assessing the performance of the innovative projects being undertaken by the university scientists. In addition, it has been revealed in this study that the purposes (i.e. basic research vs. applied research) of innovative project influenced the level of employments of DPM and RPM, and the structures (i.e. individual vs. collaborative) of them affected the degree of the application of RPM and not DPO or DPM.

Overall, the findings have shown that the majority of the university scientists employed the PM practices highlighted, but the levels of usage of each of practices differed. The greatest degree of employment was in the use of RPM, followed by DPM and DPO usage was the lowest. In terms of the effectiveness of the use of these PM practices, they were more likely to impact on MOPS, as compared with any of the other performance criteria. In addition, a number of implications of the findings have emerged, as will be discussed later.

The following sections draw all the results together, present the main conclusions, principles, relationships, and generalisations. Moreover, the interpretation of the results and their relationship to the Research Questions, are discussed. In section 6.1, the issues related to the level of employment of the PM practices by the university scientists are presented. In section 6.2, the effects of the purpose and structure of innovative project on the level of usage of PM practices are to be considered. Section 6.3 discusses the performance criteria identified from the university scientists' point of view. In section 6.4, the effectiveness of the employment of PM practices on the performance of the projects is addressed.

6.1. The Employment of Project Management Practices

This study set out to provide a better understanding of how university scientists manage innovative projects, and what are the impacts of such management on the performance levels. In order to achieve this aim, whether they employ the PM practices identified and to what extent they use them needed to be explored. Consequently, firstly, the following research question was qualitatively addressed:

- RQ 1: to what extent do university scientists (Actor) use PM practices (Process) to manage innovative projects?

After this qualitative investigation the findings showed that university scientists appeared to employ three PM practices, i.e. DPO, DPM and RPM, in managing innovative projects. In order to obtain a more comprehensive understanding of how university scientists employ these three practices, a survey was undertaken for addressing the Research Question 1.1:

- RQ1.1: to what extent do university scientists (Actor) employ DPO, DPM and RPM (Process) in managing innovative projects?

The findings of the survey (see Table 6.1 below) revealed that the extent to which the university scientists employed the PM practices highlighted were contingent. On average, based on the values of Mean and Mode (see Table 6.1), this researcher defined the levels of employment of DPO, DPM and RPM as at the 'Medium-plus extent', 'Medium extent', and 'High extent', respectively. Moreover, based on the results of the paired-sample *t* tests, the levels of application of the PM practices by the university scientists, from highest to lowest, were RPM, DPO and DPM.

Table 6.1: Summary of the Levels of Employment of the PM Practices Highlighted

	The level of employment of PM practices					
	DPO		DPM		RPM	
N	147		147		147	
Mean (S.D.)	3.38 (.954)		2.99 (.972)		3.80 (.948)	
Mode	3		3		4	
Response to …	Frequency	Percentage	Frequency	Percentage	Frequently	Percentage
Not at all	3	2	9	6.1	2	1.4
Low extent	22	15	37	25.2	12	8.2
Medium extent	55	37.4	54	36.7	35	23.8
High extent	49	33.3	41	27.9	62	42.2
The highest extent	18	12.2	6	4.1	36	24.5
Overall extent of use	Medium-plus		Medium		Upper Medium	
Paired sample *t* test:						
DPO-DPM	t (146) = 6.602, p<0.001					
DPO-RPM	t (146) = -5.258, p<0.001					
DPM-RPM	t (146) = -13.537, p<0.001					

Based on the findings, most university scientists claimed that they always defined project objectives and milestones at the beginning of innovative projects, but these may be redefined during the project life cycle. In addition, the level of employment of DPO was higher than the use of DPM. That is to say, from the university scientists' viewpoint, DPO rather than DPM was more likely to be viewed as a constant during the project' duration. Possible explanations are that, firstly, in the context of innovative projects, it is difficult for the project objective and milestones to remain well-defined throughout the whole project life cycle, as such projects are seen as highly uncertain (Turner & Cochrane, 1993). Secondly, DPO is likely to be seen as the strategic objectives or long-term project milestone (Salomo et al., 2007), and, in turn, DPM is more likely to be seen as a daily or weekly 'objective', e.g. experiment needing to be done in order to achieve the project objective. Moreover, the "results of experiments determine the subsequently milestones" that [approaches used to undertake the following experiments] (Scientist G1).

The following describes a project developing vaccine as an example to illustrate this observation. Vaccine development is usually a long-term project, including many stages. In general, the major stages of development before clinical trial are:

identifying of the pathogen, characterising of the pathogen, defining the antigen and its gene fragment, expressing the gene fragment, purifying the antigen, and producing the vaccine. These stages can be seen as milestones in the whole development project and as the strategic objective of the tasks to be conducted in each stage, for example, the stage of expressing the DNA (gene) fragment consisting of a large number of experiments, such as constructing the plasmid (i.e. one of gene expressing systems) with the target DNA fragment and selecting an appropriate host, has to be carried out. If the completion of the stage of expressing the gene fragment is viewed as a project, successfully expressing the gene fragment is the project objective, and constructing the plasmid and selecting an appropriate expressing host are two project milestones. Even the construction of the plasmid and selecting an appropriate expressing host can be seen as project objectives and experiments to approach these two objectives are viewed as project milestones.

About 42% of the respondents in the survey indicated that they tended greatly towards *regularly* monitoring project progress when they were undertaking innovative projects. It was revealed that the university scientists monitored project progress through *regular* and *irregular* communications; indeed, they stated that *regular* progress monitoring was more likely to be applied to those projects that other stakeholders, e.g. collaborators or funding bodies, were involved in. In fact, the university scientists did monitor project progress quite often through *irregular* communications, e.g. daily or weekly based informal communications or discussions. For instance, following the development of the vaccine projects mentioned previously, research team members could discuss with the PI as soon as the result of an experiment for constructing the expressing plasmid had turned out. If the result turned out to be on an unexpected track, they may immediately have redefined their approach, by re-assessing the project milestones, and even the objectives, during the discussions.

Comparing traditional PM practices with the findings of this study, it has been observed that the university scientists used a more organic approach, taking into account a wider range of PM criteria. From the university scientists' point of view, they are focused on dealing with project milestones in accordance with the progress and the results of experiments (referring to milestones) through informal and formal communications, when they are undertaking innovative projects. The findings in this work, in relation to the employment of DPM in innovative projects, were more concerned with contingency or uncertainty defining as compared with traditional PM practices and theories, echoing prior studies on project and innovation management (e.g. Andersen, 1996; Brown & Eisenhardt, 1995; Cohen et al., 1999a, 1999b; Dvir &

Lechler, 2004; van der Panne et al., 2003).

6.2. Effects of the Purpose and Structure of Innovative Projects

This section discusses the influences of the purpose and structure of innovative projects on the level of employment of PM practices by university scientists. Some of the PM literature has suggested that the process of employing PM practices in different forms of projects should vary, e.g. radical New Product Development (NPD) projects, that feature a higher degree of innovativeness, may require a different management approach, as compared with that used in incremental or moderate innovations (e.g. Salomo et al., 2007; Song & Montoya-Weiss, 1998). In addition, based on the findings in the exploratory phase and the literature (e.g. Chiesa & Frattini, 2007), the extent of employing PM practices by the university scientists to individual (academic) projects differed to that of collaborative (commissioned) projects. For instance, the university scientists interviewed claimed that they tended to retain the defined project objectives and milestones when they were undertaking collaborative projects. This is because such projects are usually highly associated with other stakeholders' strategic objectives, e.g. industrial collaborators' business plans. However, individual projects are usually characterised by lower pressures on tangible results and deadlines than collaborative ones. Under such circumstances, the project efficiency may not be an important consideration of the university scientists involved and this may lead to them adopting different approaches towards managing individual and collaborative projects.

Therefore, it was posited in this study that the purpose and structure of an innovative project may have an impact upon the application of PM practices by university scientists. In order to examine the influences, independent-sample *t* tests were employed to address the revised Research Question 2.1:

- RQ 2.1: how do the structure and purpose of innovative projects impact on the levels of employment of DPO, DPM and RPM (Process) by university scientists (Actor)?

The findings of the statistical examinations demonstrated that the purposes of innovative project influenced the level of employment of DPM and RPM by the university scientists, but the structure of project only influenced the application of RPM.

The purposes of the innovative projects significantly influenced the extent of use of DPM and RPM; moreover, the levels of use of these two PM practices in applied research were higher than in basic research. Possible explanations for these findings are as follows. Firstly, DPO is more likely to be seen as a long-term strategic objective in both basic and applied research projects (Roussel et al., 1991; Salomo et al., 2007). In light of this, DPO can not often be changed during the project life cycle; otherwise the researchers may lose their focus, which is harmful to projet effectiveness and efficiency. In addition, as it is a long-term strategic objective, DPO is less likely to deal with technical uncertainty (Lewis, Welsh, Dehler, & Green, 2002), resulting in it being insignificantly correlated with fast changing technological environments (Griffin, 1997). In other words, DPO is less likely to be redefined by university scientists than DPM, and contributes less to managing innovative projects on a daily or weekly basis. Adopting the vaccine-developing project as an example helps to explain these statements. The influence of a technological breakthrough in gene cloning techniques is on the milestones regarding the expression of the antigen gene. However, this breakthrough would not affect the projects objective, i.e. successfully developing a vaccine.

The structure of an innovative project only significantly influenced the level of usage of RPM, and the level of its application to collaborative activities was greater than for those of an individual nature. This observation could be explained as follows. Usually, individual projects are seen as having lower pressures for tangible results and deadlines than collaborative types, and have an environment that favours individual work rather than teamwork (Chiesa & Frattini, 2007). In other words, in collaborative projects, e.g. NPD, many people belonging to different functional areas (e.g. development, production) are put together into multifunctional teams to accomplish precise and defined results. In this case, monitoring project progress through *regular* communications (i.e. RPM) is a more critical issue than in individual projects, where tasks are mainly individual or organised according to an input-oriented model, e.g. the progress and results of experiments in innovative projects (Chiesa, 2001).

That is to say, university scientists are likely to be driven by other stakeholders, such as collaborators and funding bodies, to monitor project progress through *regular* research meetings, when they are carrying out collaborative projects. This is because the other stakeholders are less likely to be able to discuss project progress on a daily or weekly basis. By comparison, university scientists can check project progress with internal research members through informal discussions or communications, from time to time, in addition to the scheduled *regular* research meetings. This is because individual projects seldom involve other stakeholders during the execution stage (Chiesa, 2001). For example, in Taiwan, the NSC hardly ever reviews the project progress of individual projects during the project life cycle, but the NSC might not grant further research funding to those who do not make advances or contributions to the scientific community, e.g. publishing SCI papers or presenting cutting-edge results.

The findings of this work presented that the contextual variables, i.e. purpose and structure, affected the level of employment of PM practices, particularly DPM and RPM. Should these two variables be viewed as mediators or moderators? Baron and Kenny (1986) described the functions of being a moderator and a mediator as:

> *"the moderator function of third variables, which partitions a focal independent variable into subgroups that establish its domains of maximal effectiveness in regard to a given dependent variable, and the mediator function of a third variable, which represents the generative mechanism through which the focal independent variable is able to influence the dependent variable of interest" (p. 1173).*

Whilst this definition is developed from psychology, it has been adopted by several authors in management literature (e.g. Bonner et al., 2002; Salomo et al., 2007). Based on it, both the moderator and mediator are third variables, which are strongly associated with the independent variable. A high effect on the dependent variable by this third variable would usually qualify it as a moderator, whereas if there was a lower effect it would usually be considered to be a moderator. However, in this study the purpose and structure were not treated as the third variables during the data analysis and therefore no conclusion can be drawn, as to whether they are moderators or mediators. In addition, concerning the procedure for determining moderating and medicating effects, this study was unable to determine whether the purpose and structure of innovative project act as moderators or mediators. To assess the moderation and mediation effect, the first step would be to determine whether there is a cause effect relationship between independent variables and dependent variables, and this should be performed by regression examination (Aiken & West, 1991; Baron & Kenny, 1986). However, in the conceptual framework, the contextual factors were seen as independent variables and the levels of use of the PM practices identified by university scientists were treated as dependent variables, i.e. the two factors were not acting as the third variable outside of the independent and dependent variables.

Although the statistical examinations were not able to determine whether the contextual factors were moderators or mediators, the qualitative data indicated that the purpose and structure of the innovative projects were more likely to act as mediators. This is because a mediator is more involved in the influence on the intention, whereas the moderator is more committed to a predictor variable (Baron & Kenny, 1986). For example, in the qualitative data set, most interviewees claimed that these two factors could affect their level of use of the PM practices, i.e. their intention to use PM practices. However, there was no evidence showing these two factors could predict the level of employment of the practices.

In sum, no matter what the purpose and structure of the innovative projects, the university scientists frequently monitored project progress with project milestones (and/or objectives), even on a daily basis. However, *regular* progress monitoring was more likely to be employed by them during collaborative projects, most likely being driven by the requests made by the other stakeholders, who were interested in current project progress, during the project life cycle.

6.3. Measurements for the Performance of Innovative Projects

Some PM literature has suggested that project performance is defined and measured in terms of time, cost and scope. However, the criticism has been raised that this view is too narrow and does not include project performance criteria, such as stakeholder satisfaction and numbers of SCI papers published. The latter is particularly relevant in the innovative projects being carried out by university scientists, as 85% of respondents in the survey indicated that the numbers of SCI papers published was an important factor they used to measure the performance of these projects. In order to investigate the influence of the application of PM practices on the performance of innovative projects, more comprehensive project performance criteria have to be defined from the university scientists' point of view. However, because the literature does not provide a single interpretation for innovative projects in the context of this study, this concept has been explored through the following research question in the exploratory phase:

- RQ 3: how do university scientists (Actor) measure the performance of innovative projects (Outcome)?

The exploratory research based on the university scientists interviewed highlighted four criteria to measure the performance of innovative projects being undertaken by them. These criteria are MOPS (Meeting Objective within Proposed Schedule), AO (Achieving Objective), CRRF (Continuously Receiving Research Funding) and SCI (Numbers of SCI Papers Published). Moreover, these findings were employed in the explanatory phase, in order to address the Research Question 3.1:

- RQ 3.1: to what extent do innovative projects undertaken by university scientists achieve the performance criteria of the projects, in terms of MOPS, AO, CRRF and SCI (Outcome)?

Table 6.2 below provides a summary of the findings from the survey. The explanatory research shows that, with regard to MOPS, AO and CRRF, it was found that the levels of achievement were at the 'Upper medium extent', 'Upper medium extent' and 'High extent', respectively. Moreover, it was found that on average 4-6 SCI papers had been published or accepted, based on the value of the Mean of the categories being 2.09, which is substantial.

Table 6.2: Summary of the Levels of Achievement of Performance Measurement

	The level of achievement of performance measurement							
	MOPS		AO		CRRF		SCI	
N	147		147		147		143	
Mean (S.D.)	3.59 (.935)		3.86 (.922)		4.06 (1.160)		2.09 (1.321)	
Mode	4		4		5		1	
Response to …	F	P	F	P	F	P	F	P
Not at all (1-3 SCI papers)	4	1.4	3	2	7	4.8	65	45.5
Low extent (4-6 SCI papers)	14	9.5	8	5.4	9	6.1	37	25.9
Medium extent (7-9 SCI papers)	41	27.9	32	21.8	25	17	20	14.0
High extent (10-12 SCI papers)	68	46.3	68	46.3	33	22.4	5	3.5
The highest extent (13 and Above SCI papers)	20	13.6	36	24.5	73	49.7	16	11.2
Overall extent of achievement	Upper medium		Upper medium		High		4-6 SCI paper	

F = Frequency; P = Percentage (%)

The findings of this study have shown that the time and scope objectives, i.e. MOPS and AO, from the university scientists' point of view, were two criteria employed to assess the performance of innovative projects that they were involved in. These two criteria are linked to the traditional PM perspective, in which the employment of PM practices are supposed to ensure the efficiency and success of the projects (e.g. PMI, 2004). However, they are contradictory to traditional innovation management, in which effectiveness rather efficiency is emphasised (e.g. Keegan & Turner, 2002). In addition, the university scientists also emphasised that CRRF and SCI should be included in the project performance criteria of the innovative projects being undertaken by them. The view that project performance criteria should not only include time and scope, is strengthened by the findings of this study.

The employment of MOPS and AO as the performance criteria in innovative projects is consistent with traditional PM theory, and the findings related to the level of such use have suggested that the university scientists have paid attention to reaching project objectives efficiently, rather than just achieving them. That is, they have tended to undertake innovative projects with the intention of meeting project objectives within the agreed schedule. However, this is inconsistent with traditional innovation management theory, which has suggested that providing scientists with the best facilities and an environment with abundant resources, and then waiting for significant outcomes, would ensure success (Keegan & Turner, 2002; Miller, 1986; Omta & de Leeuw, 1997). For example, Hamel and Pralahad (1989) stated " … put a few bright people in a dark room, pour in some money and hope that something wonderful will happen" (quoted in Omta & de Leeuw, 1997, p. 224).

CRRF and SCI as performance criteria for innovative projects are the dimensions of performance that differ from those of efficiency. These two criteria are seldom seen in innovation management literature; however, they were emphasised by the university scientists interviewed. One of the theoretical explanations is that the selections of performance measurements should be linked to the reference standards, i.e. the norms to measure performance against (Kerssens-van Drongelen & Cook, 1997; Pawar & Driva, 1999; Stainer & Dixon, 2003). In other words, the selection of performance criteria is dependent on the performance dimensions to be monitored, and the context of the projects being undertaken. As a result, the chosen criteria should take each monitored dimension into account, e.g. the project purpose, the single researcher, or the whole function of the project (Frattini, Lazzarotti, & Manzini, 2006).

In practice, the university scientists viewed CRRF as a management practice employed by top management and funding bodies to encourage the efficiency and effectiveness of the innovative projects. For example, the European Commission (EC) has started paying research funding by instalments, depending on whether the progress and outcomes of the project are satisfied (Unit B.2, 2002a, 2002b). The university scientists interviewed in over half of the projects investigated claimed that their projects could be evaluated as a success, because follow-up research funding had been given to them. Moreover, based on the interview statements, it was acknowledged that this measurement would effectively motivate the university scientists to pay attention to the efficiency and effectiveness of the projects, in which they were involved. This was because CRRF was affected by MOPS, and it was significantly correlated with SCI, the latter being a vital criterion from university scientists' point of view, as will be discussed in next paragraph.

As publishing SCI papers is of great importance in improving university scientists' academic careers and professional status in the scientific community (Herbertz & Muller-Hill, 1995), they view this criterion as a very important measurement. Moreover, it has been suggested that the greater the numbers of SCI papers published, the higher the number of successful project outcomes (e.g. Boffo et al., 1999; Hellstrom & Jacob, 1999; Herbertz & Muller-Hill, 1995; Narin et al., 1997). In fact, in Taiwan, publishing SCI papers is closely associated with the achievement of their promotion and successful application for research grants. It is probably for this reason that SCI has been heavily weighted as a criterion for measuring the performance of the innovative projects in which they are involved.

In sum, the findings suggest that CRRF and SCI, as performance criteria for the innovative projects, should be included along with the traditional measures, e.g. MOPS, when university scientists are engaged in such works.

6.4. Impacts from the Employment of Project Management Practices

Some literature, although inconclusive, has suggested that using traditional PM practices may not contribute to the performance of innovative projects, as such projects are seen as uncertain and unstructured (e.g. Kerssens-van Drongelen & Bilderbeek, 1999; Turner & Cochrane, 1993), and university scientists prefer to work in an environment in which project management is absent (e.g. Cohen et al., 1999b). However, other literature (e.g. Cohen et al., 1999a; Turpin & Deville, 1995; Turpin et al., 1996) has revealed that university scientists appear to have adopted a working environment where project management is applied, when they are conducting collaborative projects. In addition, this study demonstrated that although there was some evidence of the use of traditional PM practices in collaborative projects, there was little evidence of such practices being used individually. In practice, PM practices were employed in the innovative projects, by the university scientists, through a wider set of processes.

Regressions were employed to investigate whether the employment of the PM practices identified positively contributes to the performance of the innovative projects being undertaken by the university scientists, in terms of the four criteria highlighted. And then, the following research question was addressed:

- RQ 4.1: what impacts does the employment of DPO, DPM and RPM (Process) have on the performance of innovative projects in terms of MOPS, AO, CRRF and SCI (Outcome)?

In order to address the research question by regressions, the levels of application of the PM practices identified were defined as the dependent variables, and the levels of achievement of the performance criteria highlighted were defined as the independent variables (for example, see Figure 5.4).

This study has revealed that the employment of PM practices highly and positively contributes to the performance of innovative projects in terms of MOPS and AO, moderately contributes to CRRF, and insignificantly contributes to SCI. In addition, the level of influence on MOPS is higher than on AO. Table 6.3 below summarises the contributions of the use of the PM practices identified to the performance of the innovative projects that university scientists were involved in. Overall, the findings indicate that the employment of PM practices was more likely to contribute to the level of achievement of MOPS, as compared with the other criteria. This is consistent with those PM theorists who have claimed that the use of PM practices ensures the efficiency of projects (e.g. PMI, 2004), but inconsistent with conventional innovation management theory, which has claimed that the effectiveness, rather than the efficiency, should be emphasised (e.g. Keegan & Turner, 2002).

Table 6.3: Summary of the Effectiveness of Employment of PM practices Identified

Dependent variable	Independent variable	Standardised coefficient	Adjusted R^2	Conclusion
MOPS	DPO	.481***	.226	Moderately contribute to MOPS
	DPM	.643***	.398	Considerably contribute to MOPS
	RPM	.587***	.340	Moderately contribute to MOPS
	DPM-RPM[a]	.439***-.275***	.432	The most contribute to MOPS
AO	DPO	.414***	.166	Moderately contribute to AO
	DPM	.495***	.240	Moderately contribute to AO
	RPM	.500***	.245	Moderately contribute to AO
	DPM-RPM	.301***-.281***	.280	Moderately contribute to AO
CRRF	DPO	.133	.011	No significance
	DPM	.140	.013	No significance
	RPM	.192*	.030	Some contribute to CRRF
SCI	DPO	-.040	-.005	No significance
	DPM	-.015	-.007	No significance
	RPM	-.024	-.007	No significance

[a] indicating the use of DPM and RPM together to be the independent variable
*p<0.1, **p<0.05, ***p<0.001

In terms of MOPS and AO, the findings suggest that the levels of achievement of these two performance criteria can be positively and significantly predicted by the employment of the PM practices highlighted either individually, or DPM and RPM together. Moreover, the greatest contribution to MOPS and AO is made when DPM and RPM are applied together. That is, that frequently monitoring project progress with project milestones, through informal and formal communications, considerably enhances the level of achieving project objectives within the agreed time-span, i.e. MOPS. This is consistent with previous PM and innovation literature. The former has proposed that PM practices are greatly concerned with the efficiency and effectiveness of projects (e.g. PMI, 2004); the latter has posited that "widespread formal and information communications" (Keegan & Turner, 2002, p. 369) are necessary. This reinforces the argument that PM practices could and should be employed in innovative projects (e.g. Cohen et al., 1999a; Schmid & Smith, 2002). For instance, the university scientist and industrial manager in project A emphasised that they often discussed and designed experiments, in accordance with project progress and outcomes, outside of the *regular* research meetings requested by the NSC, the funding body.

In addition, the findings imply that the employment of DPM and RPM together, by university scientists is a matter of synergy between the individual applications of the PM practices highlighted. In other words, whilst many studies have focused on the role of individual PM practices (Sullivan, 1988), a more holistic approach to employing them is more likely to secure maximum benefit (Clark & Fujimoto, 1991). Generally, it has been observed that benefits are often simultaneously claimed to have resulted from a number of initiatives. Moreover, it has been suggested that using a single PM practice in isolation may be not helpful to gaining benefits, as in reality both academics and practitioners do not appear to have isolated the contribution of individual PM practices (Clark & Fujimoto, 1991; Maylor, 2001). One issue that arises from the findings in this study is that interaction effects between the individual PM practices used, should be expected. For instance, several interviewees from the universities mentioned that employing project objectives and/or milestones to monitor project progress was a relatively natural step. However, this finding does not refute the application of DPO, DPM and RPM together in predicting the performance of innovative projects, although such holistic application was excluded by the regression examination, when a stepwise method was applied. This exclusion could be due to the strong relationship between DPO and DPM and RPM, i.e. the effect of multicollinearity on DPO.

Regarding CRRF, the results indicated that only the employment of RPM by university scientists significantly, but only slightly, affected the performance of innovative projects. In other words, the use of PM practices contributes little to the level of achievement of receiving follow-up research funding and other factor(s) influencing this most likely exist. Moreover, taking the Pearson correlation into account, the influence of the application of RPM on CRRF is likely to be mediated by MOPS, as CRRF and MOPS are significantly correlated with each other, and the employment of RPM contributes to both CRRF and MOPS. This argument is based on a consideration of the function of a mediator, which is defined as: “the mediator function of a third variable, which represents the generative mechanism through which the focal independent variable is able to influence the dependent variable of interest” (Baron & Kenny, 1986, p. 1173).

Moreover, integrating the findings regarding CRRF into MOPS and AO, it is seen that the application of PM practices made a greater contribution to MOPS, than to AO. That is, the use of PM practices is more likely to contribute to the efficiency of the projects, echoing the discussion presented previously. In addition, this finding indicates that, today, the management of innovative projects that the university scientists are involved in should not only focus on effectiveness, but also the efficiency should be taken into consideration. The results of this study have suggested that attention should be paid to both the efficiency and effectiveness of innovative projects, if university scientists want to secure their follow-up research funding. This accords with traditional innovation management theory, where CRRF has been viewed as closely linked to successful project outcomes (e.g. Keegan & Turner, 2002). In other words, achievement of the project objectives is not sufficient in order to obtain follow-up research funding, and meeting the objective within the agreed schedule is more likely to attain this result.

With respect to SCI, the findings of the survey showed that there was no evidence that the employment of PM practices influences SCI, and this was inconsistent with the exploratory research, in which the application of RPM seemed to moderately contribute to increasing the publication of SCI papers. Such inconsistency may be attributed to the design of the scale of measurement of SCI, as will be discussed in research limitations section in the next chapter.

The findings suggest that the employment of PM practices may have an indirect influence on SCI through CRRF, as the latter two exhibit significant correlation. Moreover, regarding Baron and Kenny’s (1986) definition of the functions of a moderator and a mediator, as presented above, this study has not been able to determine whether CRRF is a moderator or a mediator, between the use of PM practices and the numbers of SCI papers published. This is because the results have shown there is no significant effect of the use PM practices on SCI.

Chapter Seven: Conclusion and Proposals for Further Work

This study has explored the issue of how university scientists manage innovative projects, focusing on the employment of the PM practices identified when they are undertaking such projects. In particular, it has investigated, whether and how they employ PM practices, what effect the use of PM practices has on the performance of innovative projects, and whether such applications are influenced by the purpose (i.e. basic research vs. applied research) and structure (i.e. individual vs. collaborative). The empirical findings have been presented in Chapters Four and Five, and discussed in Chapter Six. This chapter will begin by considering the limitations of this work, and then its contribution to the debate will be assessed based on the aim, empirical findings and discussions. Finally, proposals for further work are put forward.

7.1. Limitations

7.1.1. Limitations Related to Executing this Study

One strategy related limitation concerns the qualitative data in the exploratory research, which aimed to obtain a rich and detailed view of the influence of the employment of PM practice on the performance of innovative projects, from the university scientists' point of view. To achieve the ideal aim of being as objective as possible, it would have been worthwhile for more than one researcher to be involved in the study for the purpose of minimising biases (Bryman, 2001). In addition, the aspect of the subjective bias of the respondents needs to be addressed. The university scientists interviewed have provided information regarding the employment of PM practices, the evaluation of the performance and the possible patterns between the application and the performance. The information given by them might have over emphasised their employment of PM practices, so as not to be seen as disorganised or too unstructured in their methods.

Another limitation relates to the findings about the degree to which the university scientists understood and adhered to the terminology of PM practices, as suggested in the literature. Although the employment of PM practices is a self-evidently correct process (Williams, 2005), little evidence exists on the extent to which university scientists follow logical or rational process stages or to what degree they deviate from the optimal processes associated with the employment of PM practices. They may have employed PM practices through their own perception, outside of PM theory, and hence it may be inappropriate to argue which process of employing PM practices is better. However, the process suggested in this study is based on the assumption that university scientists follow their own experience in managing innovative projects.

7.1.2. Limitations Associated with Research Methods

A further limitation related to the robustness of the exploratory research findings may have resulted from the limited amount data that was available. Overall, there were twenty-one interviewees, including twelve university scientists. However, the depth and level of detail of the information gained through the interviews, although satisfactory from the point of view of this researcher (concept saturation), may be considered questionable by others. The question as to whether including more interviewees would have provided a more comprehensive view of how the use of PM practices impacts on the performance of innovative projects, is open to debate. Thus, one may even question the comprehensiveness of the survey. Driven by the findings of the exploratory research, the survey only tested the applications of PM practices by university scientists in the biotechnology sector. As a consequence, the findings of this study may display, overall, only a restricted view of university scientists' reality, with regard to the employment of PM practices and the management of innovative projects.

As discussed in the literature review, innovative projects may be evaluated differently, depending on performance dimensions and project contexts, e.g. structure and purpose (Chiesa & Frattini, 2007). However, this study has only concentrated on the perceptions of university scientists in the biotechnology sector and their views concerning what constitutes project performance may not be shared by other stakeholders. Moreover, the findings demonstrate that the structure and purpose of innovative projects influence the use of the PM practices highlighted, suggesting that different performance criteria, to those expected from traditional PM theory, may be emphasised when the projects are being undertaken. For instance, the work has shown that there was a higher level of employment of RPM in collaborative projects, most likely resulting from the requests made by other stakeholders or the pressure for the efficiency of the projects. Hence, the performance criteria should not be restricted to just a few phenomena. This study has provided an interpretation of the assessment of the performance of innovative projects, from both the industrial managers' and university scientists' points of view; such opinions may not incorporate the perceptions about the evaluation of the project performance of other stakeholders, such as funding bodies and policy makers.

7.2. Contributions to knowledge

The findings demonstrated that three PM practices, i.e. DPO, DPM and RPM, and four measurements, i.e. MOPS, AO, CRRF and SCI, were used for assessing the performance of innovative projects. The levels of employment of these PM practices can be defined as to the: ‘Medium-plus extent’, ‘Medium extent’ and ‘Upper medium extent’, regarding DPO, DPM and RPM, respectively. The order of the levels of usage, from highest to lowest, was RPM, DPO and DPM. Moreover, the levels of achievement of the performance criteria were: MOPS at the ‘Upper medium extent’ level, AO at the ‘Upper medium extent’ level, CRRF at the ‘High extent’ level, and SCI publications at ‘four to six papers’. This is useful information, as it is based on the practices they employed rather than general statements of intent. Also, it revealed the university scientists tended to employ PM practices when they were undertaking innovative projects.

Overall, the use of these practices would be useful in predicting the levels of achievement of MOPS and AO, but may be not those of CRRF and SCI. This is because, in reality, the employment of PM practices significantly predicted the level of achievement of MOPS, AO, but there was only a slight significance regarding CRRF. Moreover, based on the findings of Pearson correlation, only MOPS was significantly correlated with CRRF, and the latter was significantly correlated with SCI. This researcher proposes that the employment of PM practices would predict the level of achievement of MOPS and CRRF, and thus may indirectly predict the level of achievement of SCI.

The employment of PM practices made the greatest positive contribution to the achievement of MOPS, followed by AO and CRRF, in the order from highest to lowest. Furthermore, the greatest predictive power to the level of achievement of MOPS and AO was made by the employment of DPM and RPM together. Only the employment of RPM was significantly able to predict the level of achievement of CRRF. Moreover, the use of RPM was significantly correlated with the employment of DPO and DPM. Based on this, it is argued that the use of RPM would be the central theme regarding the usage of PM practices, and would positively contribute to the four performance criteria highlighted to different extent levels.

The findings in this study have supported PM theory, and they may add to it, in that the usage of PM practices could positively contribute to the publishing of SCI papers, which is usually the outcome of innovative projects that are seen as highly uncertain. Nevertheless, this may have positive implications for university scientists, who prioritise publishing SCI papers when working on innovative projects, because they are positively linked to their professional status and promotion prospects (Boffo et al., 1999; Cohen et al., 1999b; Hellstrom & Jacob, 1999; Herbertz & Muller-Hill, 1995; Miller, 1986). However, the findings in this study do not refute or support the argument that using PM practices would damage the creativity of innovative projects, as presented in traditional innovation management literature (e.g. Keegan & Turner, 2002). In other words, the traditional PM theory has not been found that using PM practices stifles creativity and opportunity, from university scientists' point of view.

Whilst the literature (e.g. Cohen et al., 1999b; Miller, 1986; Sapienza, 2005) has suggested that university scientists usually enjoy a working environment where there are high degrees of freedom and autonomy when they are undertaking innovative projects, the findings of this study have revealed that their levels of use of PM practices could be affected by the context. When the projects were for a particular purpose (e.g. applied research for seeking a precise application from the outcomes of basic research), or a certain structure (e.g. involving other outside stakeholders, including collaborators, funding bodies), university scientists would vary their usage of PM practices. For instance, the level of employment of PM practices by university scientists could be driven by outside factors (e.g. project purpose, other stakeholders). In fact, this study found that the levels of employment of DPM and RPM in basic research projects were lower than those for applied research (referring to project purpose), and the degree of employment of RPM in collaborative projects was higher than in individual ones (i.e. involving outside stakeholders).

All of the above leads to the implications that:

- University scientists tend to employment PM practices when they are undertaking innovative projects, as the average level of usage was to the 'Medium extent' at least;
- From the university scientists' point of view, the measurements concerning the efficiency (e.g. MOPS) and effectiveness (e.g. CRRF and SCI) are applied to assess the performance of the projects in which they are involved;
- The efficiency and effectiveness of the projects, rather than effectiveness *only* is more likely to be the condition to receive follow-up research funding;
- Continuously receiving follow-up research funding could positively contribute to the numbers of SCI papers published and vice versa, because these two were significantly correlated with each other;
- The employment of RPM (referring to *regular* and *irregular* research meetings) appears to be the most important practice, compared with the other two practices,

as shown by their effectiveness on the performance measurements, based on the regression analyses;

- RPM appears to be the platform facilitating a contingent approach to employing PM practices, particularly using DPM. This is because the three highlighted PM practices were significantly correlated with each other, and the level of change of DPM during the project life cycle was higher than that of DPO. In addition, the higher level of change of DPM appeared to be needed to deal with technological uncertainty, as discussed previously;
- The consideration of a single PM practice in isolation may be not helpful in obtaining real benefits; instead, a more holistic approach may be needed to achieve maximum benefit from the application of PM practices. This is because, as this study found, the employment of DPM and RPM together made the greatest contribution to the achievement of MOPS and AO, as compared with the predictive power of using individual practices; and
- Variation in the purposes (i.e. basic research vs. applied research) and structures (i.e. individual vs. collaborative) of innovative projects would require differentiation in the selection of the performance criteria and managerial approaches.

In sum, university scientists employ some of the PM practices highlighted in managings, not only collaborative (commissioned) but also individual (academic) innovative projects. Nevertheless, they appear to do so through holistic and contingent approaches, where dynamic processes involving PM practices are employed during the project life cycle. That is to say, the establishment of relatively static planning process structures and adherence to the predefined project plan appear to be less appropriate in the cases of innovative projects, as compared with the dynamic approaches. These results are some distance away from those that would be expected according to traditional PM theory.

7.3. Theoretical Implications

Overall, the theoretical implication of this thesis revolve around the understanding of how university scientists employ DPO, DPM and RPM in managing innovative projects, and the impacts of such employment on the performance of such projects. Particularly, the implications concern the differences between the empirical findings of this study and previous literature, regarding the management of innovative projects and industrial scientists.

Based on the implications, this study proposes a theory that would contribute to making a connection between the employment of PM practices and the numbers of the publications of SCI papers. This theory is stated as:

When university scientists are undertaking innovative projects, they are more engaged in the process of formal and informal communications (RPM) to facilitate the process regarding the definition/redefinition of project milestones (DPM), as compared with project objectives (DPO). This could enhance the levels of achievement of meeting project objectives within the planned schedule (MOPS), and to receiving follow-up research funding (CRRF). Ultimately, the enhanced level of achievement may lead to an increase in the numbers of publications of SCI papers. In addition, the level of usage of PM practices could be affected by variation in the purpose (basic vs. applied research) and structure (individual vs. collaborative) of the innovative projects.

The elements for building up this theory will be presented below, and Figure 7.1 illustrates it.

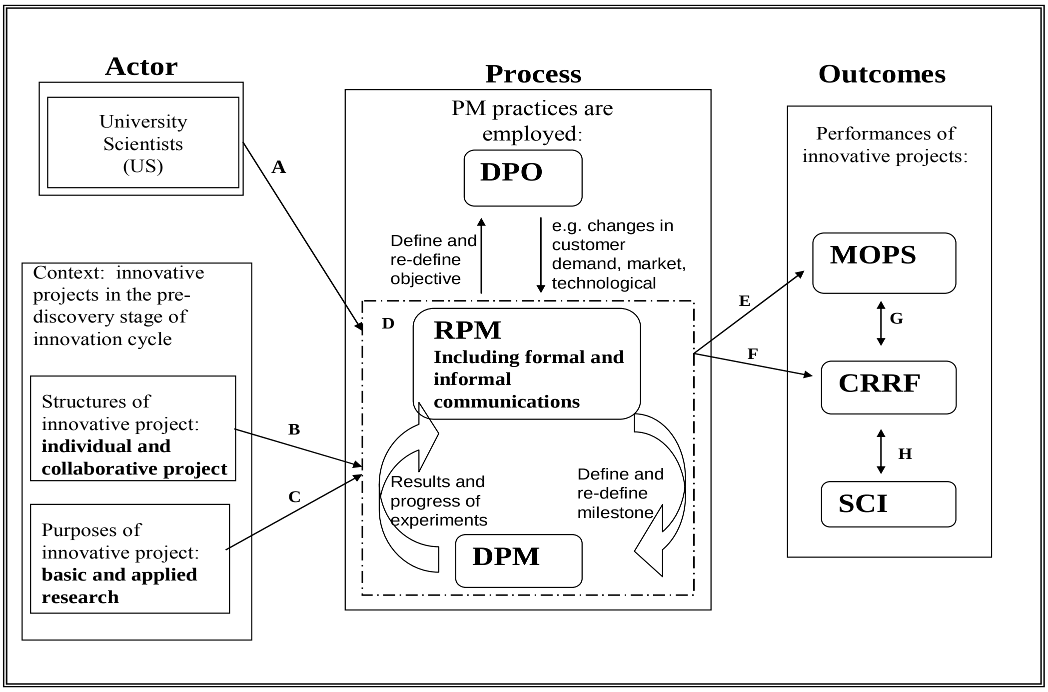

Figure 7.1: A Theoretical Model Showing the Impact of Employment of PM Practices on the Performance of Innovative Projects

The results of this study have, firstly, suggested that the boundaries of the employment of PM practices by university scientists has been extended from collaborative (commissioned) to individual (academic) projects. From the literature point of view, this was an unexpected result, as it has been argued that university scientists considered the employment of PM practices to be harmful to their creativity and professional status, and do not tend to apply them (Cohen et al., 1999b; Miller, 1986). However, they may use such practices to manage collaborative projects, e.g. UICs, so as to conduct them efficiently (Cohen et al., 1999a; Dodgson, 1993; Schmid & Smith, 2002; Turpin & Deville, 1995). However, the findings of this study have revealed that university scientists, indeed, employ PM practices in both individual and collaborative innovatively projects, but the processes of adopting them differ. Moreover, this was also observed when the university scientists were undertaking basic or applied research projects. Arrow 'A' in Figure 7.1 shows this relationship.

Moreover, the university scientists employed the PM practices, not exclusively, but contingently, during the life cycle of innovative projects. In particular, they were more likely to apply such an approach to facilitate DPM, as compared with DPO, as the former was used more frequently in dealing with the results of short-term tasks (e.g. experiments in innovative projects), and technological uncertainty (e.g. the novelty of dealing with scientific and/or technological breakthroughs) (Greasley, 2006). That is to say, a great deal of interactivity between RPM and DPM can be seen, by which DPM would be redefined iteratively (Andersen, 1996; Blindenbach-Driessen & van den Ende, 2006; Brown & Eisenhardt, 1997; Greasley, 2006; Keegan & Turner, 2002; van der Panne et al., 2003). This process emphasises the employment RPM and DPM together, and refers to the frame indicated as 'D' in Figure 7.1.

As has been shown, the purpose and structure of innovative projects affect the level of employment of PM practices by university scientists. The purpose affects the approaches to employing DPM and RPM, and the structure influences the processes of employing RPM. These can be seen as the influences of the purposes and structures of innovative projects on the Frame 'D' in Figure 7.1, as in reality university scientists view RPM as a platform where they can discuss the progress of the project, and the definition/redefinition of DPO and DPM, particularly DPM. Thus, it has been claimed in this study that the purpose and structure of innovative projects influence the interaction between DPM and RPM more than that between DPO and RPM. These relationships are shown by arrows 'B' and 'C'. However, this process is inconsistent with traditional PM approaches, in which uncertainty is not emphasised and project monitoring and evaluation proceeds as though innovative projects can be precisely defined, planned and evaluated according to predetermined criteria (Acha, Gann, & Salter, 2005; Keegan & Turner, 2002; PMI, 2004).

The findings relating to the effectiveness of the employment of the PM practices highlighted on the performance of innovative projects showed that, from the university scientists' point of view, they were a key factor used by them in efficiently achieving project objectives within the proposed schedules (MOPS), and in contributing to receiving follow-up research funding (CRRF). That is to say, the use of PM practices is functioning as an important factor enhancing the levels of achievement of MOPS and CRRF, shown by arrows 'E' and 'F', respectively. Moreover, delivering innovative projects towards meeting their objectives within the agreed time-span (MOPS), rather than meeting project objectives (AO) is significantly correlated with the level of achievement of CRRF (indicated by arrow 'G'). The latter is significantly positively correlated with SCI (indicated by arrow 'F'). Therefore, given its detachment from these latter two criteria, the variable AO is not included in this theoretical model.

Moreover, the establishment of arrows 'G' and 'H' are based on Pearson correlation, i.e. these two arrows are with both directions. That is to say, their cause-effect relationships have not defined yet. Therefore, this study only can assert that the application of PM practices could indirectly enhance the number of the publications of SCI papers. It is suggested that this could be tested by using the approach of 'Structural Equation Modelling', that can be performed by AMOS or LISREL software (Hinton et al., 2004).

7.4. Practical Implications

University scientists deliver new outcomes of innovative projects to clients in the academic and/or industrial sectors, such as academic journals and industrial collaborators, respectively, and struggle with an increasingly complex range of client demands and technological, market and regulation changes. They also encounter the pressure to produce accountability in the efficiency and effectiveness of innovative projects. The findings of this study would encourage them to employ PM practices in order to improve the efficiency of innovative projects, ultimately benefiting their effectiveness. This is because the efficiency of such projects is significantly correlated with receiving follow-up research funding. The latter is significantly correlated with the numbers of SCI papers published and accepted (see Figure 7.1). Based on these findings, some practical implications have emerged.

7.4.1. Is It Worth Employing Project Management Practices?

Organisations such as the Project Management Institute (PMI) or the Association of Project Management (APM) claim, in their best practice standards, that through the initiating, planning, executing, monitoring and controlling and closing processes, project managers can effectively achieve expected project outcomes. In terms of the university scientists' perspective, monitoring project progress (i.e. RPM) with defined project objectives (i.e. DPO) and, in particular, project milestones (i.e. DPM), significantly enhances the level of achievement of innovative project objectives within the agreed time limits (MOPS). In addition, some of the literature (e.g. Giesecke, 2000; Kaiser & Prange, 2006; Kelly et al., 2002) has argued that the performance of innovative projects being undertaking by university scientists stifles efficiency and effectiveness. Consequently, follow-up research funding, or slack research resources (Keegan & Turner, 2002), may not be secured and ultimately this could hinder the creation of new ideas and the production of SCI papers. Hence, the results of this study suggest that using PM practices should be considered by university scientists when they are undertaking innovative projects, to secure the maximum effectiveness and efficiency of such projects.

7.4.2. Processes of Using Project Management Practices

The findings suggest that there is a synergy effect in the employment of PM practices together, for the cases of this study, the use of DPM and RPM together contributed to MOPS and AO more than the use of the other PM practices individually. It indicates that, regarding innovative projects, the application of individual PM practices is less likely to be appropriate (Keegan & Turner, 2002). Instead, the application of PM practices is recommended through a dynamic and holistic process, when they are being applied during innovative projects, e.g. redefining defined project milestones during the research meetings.

Following this, RPM appeared to be a vital practice in managing these projects, as it was in these arenas where the dynamic process of using PM practices was taking place. From the university scientists' viewpoint, communications for progress monitoring were viewed as platforms for sharing resources, ideas and knowledge to the enhance projects' progress. This echoes "collaborative approaches" (Terziovski & Morgan, 2006), where the management of knowledge across organisational boundaries and the sharing of information with partners takes place. This is particularly true in the biotechnology industry, as this industry is developing so fast and is coupled with an information explosion (Salomo et al., 2007; Terziovski &

Morgan, 2006).

In sum, the results of this study have provided valuable implications for university scientists and other stakeholders involved in innovative projects. Unless the research resources are unlimited, a greater emphasis needs to be placed by them on the core elements of PM practice, particularly in the processes of defining and/or redefining project milestones and/or project objectives, through *irregular* and *regular* progress monitoring. That is to say, by doing so the dynamic processes of using PM practices in managing innovative projects can take place. In addition, when more projects have resorted to employing PM practices, further research into the issues regarding efficiency should be carried out. This would provide supporting evidence for the theory derived from this study, and could lead to a better understanding of the management of innovative projects being undertaking by university scientists.

7.5. Further Studies

In addition to the contributions mentioned in sections 7.2 – 7.4, a few further studies for building up a more comprehensive understanding of how the main actor, university scientists, manage innovative projects, are proposed.

7.5.1. Wider Measuring Dimensions

The accuracy of the scales employed in the survey remains up for debate. The development of the scales was predominately based on the exploratory findings and relied far less on existing empirical evidence, owing to the scarcity and insufficient credibility of previously data. Inadequate choice of scale of the Numbers of SCI Papers Published may have resulted from the design of the questionnaire, and as a consequence there appeared to be no impact of the employment of PM practices on this performance criterion. In addition, the measurements for measuring to what extent the university scientists employed PM practices and met the performance criteria were single questions and this could have led to a higher degree of subjectivity in the responses. Obviously, the greater the number of measuring dimensions on a topic, the more likelihood that there will be cross verification (Bryman, 2001; Chiesa & Frattini, 2007; Tashakkori & Teddlie, 1998).

7.5.2. Extending the Boundaries of the Application of Project Management Practices

One future direction is to conduct additional research into the application of PM practices by university scientists in other sectors, such as semiconductors and telecommunications. Future research involving more sectors will be necessary to investigate the effects of context differences. In particular, research on innovative projects with different purposes or structures may reveal other contextual variables' influences on success factors for innovation. For instance, the degree of uncertainty (Meyer, Loch, & Pich, 2002) and the maturity of scientific knowledge of the biotechnology sector are different to the aforementioned industrial sectors (Cardinal et al., 2001; Gay & Dousset, 2005; Pisano, 1994, 2006). As a result of this, it may be worthwhile to determine whether the same employment of PM practices prevails in other sectors and to what extent their use impacts on the outcomes of innovative projects. In addition, by doing so, researchers could investigate how different environments affect the application of PM practices by university scientists, in managing the innovative projects they are undertaking.

Further research could examine the specific performance measures for innovative projects in which university scientists are involved and more appropriate questions posed to measure these. The traditional performance measures, e.g. time and scope, may not be adequate in assessing the performance of the projects. For example, from the university scientists' perspective, publishing SCI papers should be their most important concern, as it is highly associated with their academic careers and professional status (Cohen et al., 1999a, 1999b; Herbertz & Muller-Hill, 1995; Miller, 1986). In addition, receiving follow-up research funding is also vital in the effective implementation of innovative projects (Cyert & March, 1963; Keegan & Turner, 2002). The majority of university scientists and theorists agree that abundant research resources promote experimentation, which is essential in innovative projects, and allows for uncertainty to be absorbed (Keegan & Turner, 2002; Nohria & Gulati, 1996). This can "free managerial attention that in the event of slack [research resources] will be focused on short-term performance rather than uncertain projects" (Keegan & Turner, p.369).

As presented, the structures and purposes of innovative projects influence the level of employment of PM practices by university scientists. This may influence the selection of the performance measures (Chiesa & Frattini, 2007). This study does not explicitly take into account the effects of these two and other contextual variables on the selections of the performance criteria, for the innovative projects that university scientists are involved in. Therefore, further research could be aimed at exploring the joint effects of structures and purposes of innovative projects and other contextual factors (e.g. innovative strategy, dimensions and resources available) on the design of the performance measurement system. Moreover, the contextual factors that could be investigated, regarding this subject, are, e.g. motivation of personnel and the levels of acceptance of the PM practices and performance measurement system.

7.5.3. Contributing Effects of Project Management on the Publication of SCI Papers

The findings of this study have revealed that the applications by the university scientists of the PM practices highlighted are more likely to positively contribute to the efficiency of conducting innovative projects, but less likely to the receiving of follow-up research funding and publishing SCI papers. This implies that there may be other factors influencing the level of receiving follow-up research funding and publishing SCI papers, when they are undertaking these projects. Further research would be worthwhile to explore these factors. If the effects of the use of PM practices on the level of publications were explored and confirmed, better efficiency and effectiveness of innovative projects, in which university scientists are involved, could be expected.

The exploration of these issues will improve the understanding of the specifics of innovation management in radically innovative environments, e.g. the biotechnology industry, and even in the wider academic arena.

References

Abernathy, W. J., & Utterback, J. 1988. Patterns of industrial innovation. In M. L. Tushman, & W. Moore (Eds.), ***Readings in the Management of Innovation***, 2nd ed. New York: Harper Business.

Acha, V., Gann, D. M., & Salter, A. 2005. Episodic innovation: R&D strategies for project-based environment. ***Industry and Innovation***, 12(2): 255-281.

Afuah, A. 1998. ***Innovation Management: Strategies, Implementation and Profits***. New York: Oxford University Press.

Aiken, M., & West, S. G. 1991. ***Multiple Regression: Testing and Interpreting Interactions***. Newbury Park, CA: SAGE.

Amabile, T. M. 1996. A model of creativity and innovation in organisations. ***Research in Organizational Behavior***, 10: 123-167.

Amabile, T. M. 2001. Time to get serious about talent management. ***Harvard Management Update***, 6: 6-7.

Amabile, T. M., Nasco, C. P., Mueller, J., Wojcik, T., Odomirok, P. W., Marsh, M., & Kramer, S. J. 2001. Academic-practitioner collaboration in management research: a case of cross-profession collaboration. ***Academy of Management Journal***, 44(2): 418-431.

Amir-Aslani, A., & Negassi, S. 2006. Is technology integration the solution to biotechnology's low research and development productivity? ***Technovation***, 26: 573-582.

Andersen, E. S. 1996. Warning: activity planning is hazardous to your project's health! ***International Journal of Project Management***, 14(2): 89-94.

Anderson, A., & Tushman, M. L. 1990. Technical discontinuities and dominant designs: a cyclical model of technological change. ***Administrative Science Quarterly***, 35: 604-633.

Ashill, N. J., & Jobber, D. 1999. The impact of environmental uncertainty perceptions, decision-maker characteristics and work environment characteristics on the usefulness of marketing information systems (MkIs): a conceptual framework. ***Journal of Marketing Management***, 15: 519-540.

Ashill, N. J., & Jobber, D. 2001. Defining the domain of perceived environmental uncertainty: an exploratory study of senior marketing executives. ***Journal of Marketing Management***, 17: 543-558.

Atkinson, R. 1999. Project management: cost, time and quality, two best guesses and a phenomenon, its time to accept other success criteria. ***International Journal of Project Management***, 16(7): 337-342.

Auderetsch, D. B., Link, A. N., & Scott, J. T. 2002. Public/private technology partnerships: evaluating SBIR-supported research. ***Research Policy***, 31: 145-158.

Audretsch, D. B., & Stephan, P. 1996. Company-scientist locational linkages: the case of biotechnology. ***American Economic Review***, 86(3): 641-652.

Baccarini, D. 1999. The logical framework method for defining project success. ***Project Management Journal***, 30(4): 25-32.

Backman, K., & Kyngäs, H. A. 1999. Challenges of the grounded theory approach to a novice researcher. ***Nursing and Health Sciences***, 1(3): 147-153.

Barnes, T., Pashby, I., & Gibbons, A. 2006. Managing collaborative R&D projects development of a practical management tool. ***International Journal of Project Management***, 24: 395-404.

Baron, R. M., & Kenny, D. A. 1986. The moderator-mediator variable distinction in social psychological research: conceptual, strategic, and statistical considerations. ***Journal of Personality and Social Psychology***, 51(6): 1173-1182.

Bart, C. K. 1993. Controlling new product R&D projects. ***R&D Management***, 23: 187-197.

Belderbos, R., Carree, M., & Lokshin, B. 2004. Cooperative R&D and firm performance. ***Research Policy***, 33: 1477-1492.

Bhaskar, R. 1975. ***A Realist Theory of Science***. Leeds: Leeds Books.

BHEF. 2001. ***Working Together, Creating Knowledge: The University-industry Research Collaboration Initiative***: American Council on Education.

Biemans, W. G. 1989. ***Developing Innovations within Networks***. Eindhoven University of Technology.

Birnbaum, R. 1988. ***How Colleges Work: the Cybernetics of Academic Organisation and Leadership***. San Francisco: Jossey-Bass.

Blindenbach-Driessen, F., & van den Ende, J. 2006. Innovation in project-based firms: the context dependency of success factors. ***Research Policy***, 35: 545-561.

Boffo, S., Chave, D., Kaukonen, E., & Opdal, L. R. 1999. The evaluation of research in European universities. ***European Journal of Education***, 34(3): 325-334.

Bonner, J. M., Ruekert, R. W., & Walker Jr, O. C. 2002. Upper management control of new product development projects and project performance. ***The Journal of Product Innovation Management***, 19: 233-145.

Bremser, W. G., & Barsky, N. P. 2004. Utilizing the balanced scorecard for R&D performance measurement. ***R&D Management***, 34(3): 229-338.

Brown, S., & Eisenhardt, K. M. 1995. Product development: past research, present findings, and the future directions. ***Academy of Management Review***, 20: 343-378.

Brown, S., & Eisenhardt, K. M. 1997. The art of continuous change: linking complexity theory and time-paced evolution in relentlessly shifting organisations. ***Administrative Science Quarterly***, 42(1): 1-34.

Brown, W. B., & Gobeli, D. 1992. Observations on the measurement of R&D productivity: a case study. ***IEEE Transactions on Engineering Management***, 39(4): 325-331.

Bryman, A. 2001. ***Social Research Methods***. New York: Oxford University Press.

BSI. 2000. ***Project Management: Guide to Project Management***. London: British Standards Institute.

Buchko, A. A. 1994. Conceptualisation and measurement of environmental uncertainty: an assessment of the miles and snow perceived environmental uncertainty scale. ***Academy of Management Journal***, 37(2): 410-425.

Burns, T., & Stalker, G. M. 1961. ***The Management of Innovation***. London: Travistock.

Calantone, R., Garcia, R., & Dröge, C. 2003. The effects of environmental turbulence on new product development strategic planning. ***Journal of New Production and Innovation Management***, 20: 90-103.

Cardinal, L. B., Alessandri, T. M., & Turner, S. F. 2001. Knowledge codifiability, resources, and science-based innovation. ***Journal of Knowledge Management***, 5(2): 195-204.

Carter, C., & Williams, B. 1957. ***Industry and technical progress***. Oxford: Oxford University Press.

Casper, S. 2000. Institutional adaptiveness, technology policy, and the diffusion of new business models: the case of German biotechnology. ***Organization Studies***, 21: 887-914.

Chang, Y.-C. 2003. Benefits of co-operation on innovative performance: evidence from integrated circuits and biotechnology firms in the UK and Taiwan. ***R&D Management***, 33(4): 425-437.

Chesbrough, H. W. 2003. The era of open innovation. ***Sloan Management Review***, Spring: 35-41.

Chiesa, V. 2000. Global R&D project management and organisation: a taxonomy. ***Journal of Product Innovation Management***, 17: 341-359.

Chiesa, V. 2001. ***R&D Strategy and Organisations***. London: Imperial College Press.

Chiesa, V., & Frattini, F. 2007. Exploring the differences in performance measurement between research and development: evidence from a multiple case study. ***R&D Management***, 37(4): 283-301.

Chiesa, V., Frattini, F., Lazzarotti, V., & Manzini, R. 2007. How do measurement objectives influence the R&D performance measurement system design:

evidence from a multiple case study. ***Management Research News***, 30(3): 187-202.

Chiesa, V., & Masells, C. 1996. Searching for an effective measure of R&D performance. ***Management Decision***, 34(7): 49-57.

Christensen, C. 1997. ***The Innovator's Dilemma***. Boston: Harvard Business School.

Clark, K., & Fujimoto, T. 1991. ***Product Development Performance: Strategy, Organisation and Management in the World Automotive Industry***. Boston, MA: Harvard Business School Press.

Clark, K. B., & Fujimoto, T. 1989. Lead time in automobile product development: exploring the Japanese advantages. ***Journal of Engineering and Technology Management***, 6: 25-58.

Clawson, J. G. 1996. ***Chico Park District(s): The Information System Project***. Charlottesville: University of Virginia Darden School Foundation.

Cleland, D. I., & Ireland, L. R. 2002. ***Project Management: Strategic Design and Implementation*** (4th ed.). New York: McGraw-Hill.

Cohen, L., Duberley, J., & McAuley, J. 1999a. Fuelling discovery or monitoring productivity: research scientists' changing perceptions of management. ***Organization***, 6(3): 473-497.

Cohen, L., Duberley, J., & McAuley, J. 1999b. The purpose and processes of sciences: contrasting understanding in UK research establishments. ***R&D Management***, 29(3): 233-245.

Cohen, S. I., Chang, A., Boyer, H., & Helling, R. 1973. Construction of biologically functional bacterial plasmids in vitro. ***Proceedings National Academy of Science***, 70: 65-74.

Cohen, W. M., Florida, R., Randazzese, L., & Walsh, J. P. 1998. Industry and the academy: uneasy partners in the cause of technological advance. In R. Noll (Ed.), ***Challenges to the Research University***: 171-199. Washington DC: Brookings Institution Press.

Cohen, W. M., & Levinthal, D. A. 1990. Absorptive capacity: a new perspective on learning and innovation. ***Administrative Science Quarterly***, 35: 128-152.

Collier, D. W. 1977. Measuring the performance of R&D department. ***R&D Management***, 20(2): 30-34.

Cooper, K. G., & Kleinschmidt, E. J. 1995. Benchmarking the firm's critical success factors in new product development. ***Journal of Product Innovation Management***, 12: 374-391.

Cooper, R. G. 1983. A process model for industrial new product development. ***IEEE Transactions on Engineering Management***, 30(1).

Cooper, R. G. 1994. Perspective: third generation new product processes. ***Journal of***

Product Innovation Management, 11: 3-14.

Cooper, R. G., & Kleinschmidt, E. J. 1987. Success factors in project innovation. ***Industrial Marketing Management***, 16(3): 215-224.

Cordero, R., Farris, G. F., & DiTomaso, N. 2004. Supervisors in R&D laboratories: using technical, people, and administrative skills effectively. ***IEEE Transactions on Engineering Management***, 51(1): 19-30.

Crawford, C. M. 1980. Defining the charter for product innovation. ***Sloan Management Review***, 22(1): 3-12.

Cyert, R., & March, J. 1963. ***A Behavioural Theory of the Firm***. Oxford: Blackwell.

Czaja, R., & Blai, J. 1996. ***Designing Surveys: A Guide to Decisions and Procedures***. Pine Forge: Thousand Oaks.

Dacin, M. T., Hitt, M. A., & Levitas, E. 1997. Selecting partners for successful international alliances: examination of US and Korean firms. ***Journal of World Business***, 32(1).

Daft, R. L. 1982. A dual-core model of organisational innovation. ***Academy of Management Journal***, 21: 193-210.

Damanpour, F., & Evan, W. M. 1984. Organisational innovation and performance: the problem of organisational lag. ***Administrative Science Quarterly***, 29: 392-402.

Dasgupta, P., & David, P. 1994. Toward a new economics of science. ***Research Policy***, 23: 487-521.

Davenport, S., Davies, J., & Grimes, C. 1999. Collaborative research programmes: building trust from difference. ***Technovation***, 19: 31-40.

David, P. A., Mowery, D. C., & Steimmueller, W. E. 1992. Analysing the economic payoffs from basic research. ***Economics of Innovation and New Technology***, 21(73-90).

de Leeuw, A. C. J. 1990. ***Organisaties: Management, Analyse, Ontwerp Verandering, een Systeemvisie*** (4th ed.). Assen: van Gorcum.

Denzin, N. K., & Lincoln, Y. S. 2000. ***Handbook of Qualitative Research*** (2nd ed.). Thousand Oaks, CA: SAGE.

DeTienne, D. R., & Koberg, C. S. 2002. The impact of environmental and organisational factors on discontinuous innovation within high-technology industries. ***IEEE Transactions on Engineering Management***, 49(4): 352-387.

Dewar, R. D., & Dutton, J. E. 1986. The adoption of radical and incremental innovation: an empirical analysis. ***Management Science***, 32: 1422-1433.

Dodgson, M. 1992. The future for technological collaboration. ***Futures***: 459-470.

Dodgson, M. 1993. ***Technological Collaboration in Industry: Strategies, Policy and Internationalization in Innovation***. London: Routledge.

Downey, K. H., Hellriegel, D., & Slocum, W. 1975. Environmental uncertainty: the construct and its application. ***Administrative Science Quarterly***, 20: 613-629.

Driva, H., Pawar, K. S., & Kenon, U. 2000. Measuring product development performance in manufacturing organisations. ***International Journal of Production Economics***, 69: 147-159.

Drucker, P. 1985. ***Innovation and Entrepreneurship: Practice and Principles***. New York: Harper and Row.

Duncan, R. 1972. Characteristics of organisational environments and perceived environmental uncertainty. ***Administrative Science Quarterly***, 17: 313-327.

Duysters, G., Kok, G., & Vaandrager, M. 1999. Crafting successful strategic technology partnerships. ***R&D Management***, 29: 343-351.

Dvir, D., & Lechler, T. 2004. Plans are nothing, changing plans is everything: the impact of change on project success. ***Research Policy***, 33: 1-15.

Dvir, D., & Shenhar, A. J. 1992. Measuring the success of technology based strategic business units. ***Engineering Management Journal***, 4(4): 33-38.

Easterby-Smith, M., Thorpe, R., & Lowe, A. 2002. ***Management Research: An Introduction*** (2nd ed.). London: SAGE Publications Ltd.

Edwards, M. G., Murray, F., & Yu, R. 2003. Value creation and sharing among universities, biotechnology and pharma. ***Nature Biotechnology***, 21: 618-624.

Eisenhardt, K. M. 1989. Building theories form case study research. ***Academy of Management Review***, 14(4): 532-550.

Elkington, P., & Smallman, C. 2002. Managing project risks: a case study from the utilities sector. ***International Journal of Project Management***, 20: 49-57.

Ernst, H. 2002. Success factors of new product development: a review of the empirical literature. ***International Journal of Management Review***, 4(1): 1-40.

Ettlie, J. E. 1980. Adequacy of stage models for decisions on adoption of innovation. ***Psychological Report***, 46: 991-995.

Ettlie, J. E. 1983. Organisation policy and innovation among suppliers to the food processing sector. ***Academy of Management Journal***, 26: 27-44.

Ettlie, J. E. 1997. Integrated design and new product success. ***Journal of Operation Management***, 15: 33-56.

Ettlie, J. E., Bridges, W. P., & O'Keefe, R. D. 1984. Organisation strategy and structural differences for radical versus incremental innovation. ***Management Science***, 30: 682-695.

Ettlie, J. E., & Reza, E. M. 1992. Organisational integration and process innovation. ***Academy of Management Journal***, 35(795-827).

Etzkowitz, H. 1998. The norms of entrepreneurial science: cognitive effects of the new university industry linkages. ***Research Policy***, 27: 823-833.

Etzkowitz, H., Webster, C., Gebhardt, B., & Terra, R. C. 2000. The future of the university and the university of the future: evolution of ivory tower to entrepreneurial paradigm. ***Research Policy***, 29: 313-330.

Evan, W. M. 1966. Organisational lag. ***Human Organisations***, Spring: 51-53.

Feller, I., Ailes, C. P., & Roessner, J. D. 2002. Impacts of research universities on technological innovation in industry: evidence from engineering research centers. ***Research Policy***, 31: 457-474.

Fontana, A., & Fery, J. H. 2000. The interview: From structured questions to negotiated text. In N. K. Denzin, & Y. S. Lincoln (Eds.), ***Handbook of Qualitative Research***, 2nd ed.: 645 - 672. Thousand Oaks, CA: Sage Publications.

Ford, I. D., & Saren, M. 2001. ***Managing and Marketing Technology***. London: Thomson Learning.

Forrest, J. E., & Martin, M. J. C. 1992. Strategic alliance between large and small research intensive organisation: experiences in the biotechnology industry. ***R&D Management***, 22(1): 47-53.

Frattini, F., Lazzarotti, V., & Manzini, R. 2006. Towards a system of performance measures for R&D activities: NiKem Research case study. ***International Journal of Innovation Management***, 10(4): 425-454.

Freeman, C. 1987. ***Technology and Economic Progress: lessons from Japan***. London: Pinter.

Freeman, C. 1994. Critical survey: the economics of technical change. ***Cambridge Journal of Economics***, 18: 463-514.

Gatignon, H., Tushman, M. L., Smith, W., & Anderson, P. 2002. A structural approach to assessing innovation: construct development of innovation locus, type, and characteristics. ***Management Science***, 48(9): 1103-1122.

Gay, B., & Dousset, B. 2005. Innovation and network structural dynamics: study of the alliance network of a major sector of the biotechnology industry. ***Research Policy***, 34: 1457-1475.

Gee, R. E. 1972. The opportunity criterion - a new approach to the evaluation of R&D. ***R&D Management***, 15(3): 64-71.

George, D., & Mallery, P. 2003. ***SPSS for Windows Step by Step: A Simple Guide and Reference***. London: Pearson Education.

Gibbson, M. 1997. The translation of social needs into research agendas. In R. M. Gibbson, J. Maddox, B. Martin, & P. Papon (Eds.), ***Science in Tomorrow's Europe***: 69-78. Paris: Economica International.

Gibbson, M., Limoges, C., Nowotny, H., Schwartzman, S., Scott, P., & Trow, M. 1994.

The New Production of Knowledge: The Dynamics of Sciences and Research in contemporary Societies. Thousand Oaks: SAGE.

Giesecke, S. 2000. The contrasting roles of government in the development of biotechnology industry in the US and Germany. ***Research Policy***, 29: 205-223.

Gilley, J. W., & Fulmer, K. A. 1986. ***Searching for academic excellence: Twenty Colleges and Universities on the Move and Their Leaders***. London: Collier Macmillan.

Gittelman, M. 2006. National institutions, public-private knowledge flows, and innovation performance: a comparative study of the biotechnology industry in the US and France. ***Research Policy***, 35: 1052-1068.

Gobeli, D., & Brown, D. J. 1987. Analysing product innovations. ***Research Management***, July-August.

Gomes, J. F. S., Hurmelinna, P., Amaral, V., & Blomqvist, K. 2005. Managing relationships of the republic of science and the kingdom of industry. ***Journal of Workplace Learning***, 17(1/2): 88-98.

Gopalakrishnan, S., & Damanpour, F. 1997. A review of innovation research in Economics, Sociology and Technology Management. ***Omega***, 25(1): 15-28.

Goulding, C. 1998. Grounded theory: the missing methodology on the interpretivist agenda. ***Qualitative Market Research: An International Journal***, 1(1): 50-57.

Greasley, A. 2006. ***Operations Management***. Chichester: John Wiley & Sons Ltd.

Griffin, A. 1997. The effect of project and process characteristics on product development cycle time. ***Journal of Marketing Research***, 34: 24-35.

Griffin, A., & Page, A. L. 1996. An interim report on measuring product development success and failure. ***Journal of Product Innovation Management***, 13(6): 478-496.

Guba, E. G., & Lincoln, Y. S. 1994. ***Completeing paradigms in qualitative research***. Thousand Oaks: Sage Publication.

Hagedoorn, J. 2002. Inter-firm R&D partnerships: an overview of major trends and patterns since 1960. ***Research Policy***, 31(4): 477-492.

Hair, J., Anderson, R., Tatham, R., & Black, W. 1998. ***Multivariate data analysis***. New Jersey: Prentice-Hall International.

Hall, L. A., & Bagchi-Sen, S. 2007. An analysis of firm-level innovation strategies in the US biotechnology industry. ***Technovation***, 27: 4-14.

Hamel, G., & Pralahad, C. K. 1989. Strategic Intent, ***The Best of The Harvard Business Review***: 187-200. Boston, MA: Harvard University.

Hammersley, M. 1996. The relationship between qualitative and quantitative research: Paradigm loyalty versus methodological eclecticism. In T. E. Richardson (Ed.), ***Handbook of Research Methods for Psychology and the Social Sciences***.

Leicester: BPS Books.

Hayes, R., & Abernathy, W. J. 1980. Managing our way to economic decline. ***Harvard Business Review***(July-August).

Hayes, R. H. 1988. ***Dynamic Manufacturing***. London: Free Press.

Hellstrom, T., & Jacob, M. 1999. Evaluating and managing the performance of university-industry partnerships. ***Evaluation***, 5(3): 330-339.

Henderson, R. M., & Clark, K. B. 1990. Architectural innovation: the reconfiguration of existing product technologies and the failure of established firms. ***Administrative Science Quarterly***, 35: 9-30.

Herbertz, H., & Muller-Hill, B. 1995. Quality and efficiency of basic research in molecular biology: a bibliometric analysis of thirteen excellent research institutes. ***Research Policy***, 24: 959-979.

Hines, P. 1993. ***Mutual Competitive Advantage***. London: Financial Times - Pitman Publishing.

Hinton, P. R., Brownlow, C., McMurray, I., & Cozens, B. 2004. ***SPSS Explained***. London: Routledge.

Iansiti, M., & West, J. 1997. Technology integration: turning great research into great products. ***Harvard Business Review***, 73(3): 69-79.

Imai, K., Nonaka, I., & Takeuchi, H. 1985. Managing the new product development. In K. Clark, & F. Hayes (Eds.), ***The Uneasy Alliance***. Boston, MA: Harvard Business School Press.

Jankowicz, A. D. 1991. ***Business research for students.*** London: Chapman & Hall.

Johnsen, T., Phillips, W., Caldwell, N., & Lewis, M. 2006. Centrality of customer and supplier interaction in innovation. ***Journal of Business Research***, 59: 671-678.

Jordan, G. B., Hage, J., Mote, J., & Hepler, B. 2005. Investigating differences among research projects and implications for managers. ***R&D Management***, 35(5): 501-511.

Kaiser, R., & Prange, H. 2006. The reconfiguration of national innovation systems - the example of German biotechnology. ***Research Policy***, 33: 395-408.

Kaplan, R. S., & Norton, D. P. 1996. Using the balanced scorecard as a strategic management system. ***Harvard Business Review***, 74(1): 75-85.

Kassicieh, C., Walsh, S. T., Romig, A. D., Cumminngs, J. C., McWhorter, P., & Williams, D. 2002. Factors differentiating the commercialization of disruptive and sustaining technologies. ***IEEE Transactions on Engineering Management***, 49(4): 375-387.

Katz, R. (Ed.). 1997. ***The Human Side of Managing Technological Innovation***. New York: Oxford University Press.

Keegan, A., & Turner, J. R. 2002. The Management of innovation in project-based firms. ***Long Range Planning***, 35: 367-388.

Kelly, M., Schaan, J.-L., & Joncas, H. 2002. Managing alliance relationships: key challenges in the early stages of collaboration. ***R&D Management***, 32(1): 11-22.

Kenney, M. 1986. ***Biotechnology: The University-Industrial Complex***. New Haven: Yale University Press.

Kerssens-van Drongelen, I. C., & Bilderbeek, J. 1999. R&D performance measurement: more than choosing a set of metrics. ***R&D Management***, 29(1): 35-46.

Kerssens-van Drongelen, I. C., & Cook, A. 1997. Design principles for the development of measurement systems for research and development processes. ***R&D Management***, 27(4): 345-357.

Khilji, S. E., Mroczkowski, T., & Bernstein, B. 2006. From invention to innovation: toward developing an integrated innovation model for biotechnology firms. ***Journal of Product Innovation Management***, 23(6): 528-540.

Kimberly, J. R., & Evanisko, M. 1981. Organisational innovation: the influence individual, organisational and contextual factors on hospital adoption of technological and administrative innovations. ***Academy of Management Journal***, 24: 689-713.

Kinnear, P. R., & Gray, C. D. 2004. ***SPSS 12 Made Simple***. Hove, East Sussex: Psychology Press.

Kline, S. J. 1985. Innovation is not a liner progress. ***Research Management***, July-August: 36-45.

Kok, G., & Wildeman, L. 1998. Crafting strategic alliances: building effective relationships: KPMG Report.

Kumpe, T., & Bolwijn, P. T. 1994. Towards the innovative firm-challenge for R&D management. ***Research and Technology Management***, 37(1): 38-44.

Lane, P. J., & Lubatkin, M. 1998. Relative absorptive capacity and interorganisational learning. ***Strategic Management Journal***, 19: 461-477.

Latour, B., & Woolgar, S. 1979. ***Laboratory Life: The Social Construction of Scientific Facts***. Beverly Hills, CA: Sage Publications.

Lawrence, P. R., & Lorsch, J. W. 1967. ***Organisation and Environment***. Boston: Harvard University, Graduate School of Business Administration, Division of Research.

Leblebici, H., & Salancik, G. R. 1981. Effects of environmental uncertainty on information and decision processes in bank. ***Administrative Science Quarterly***, 26: 578-596.

Lee, Y. S. 2000. The sustainability of university-industry research collaboration: an empirical assessment. ***Journal of Technology Transfer***, 25: 111-133.

Leifer, R., McDermott, C. M., O'Connor, G. C., Peters, L. S., Rice, M. P., & Veryzer, R. 2000. ***Radical Innovation: How Mature Companies Can Outsmart Upstarts***. Boston, MA: Harvard Business School Press.

Lewis, M. W., Welsh, M. A., Dehler, G. E., & Green, S. G. 2002. Product development tensions: exploring contrasting styles of project management. ***Academy of Management Journal***, 45: 546-564.

Liebeskind, J. P., Oliver, A. L., Zucker, L., & Brewer, M. 1996. Social networks, learning, and flexibility: sourcing scientific knowledge in new biotechnology firms. ***Organization Science***, 7(4): 428-443.

Linton, J. D. 2002. Forecasting the market diffusion of disruptive and discontinuous innovation. ***IEEE Transactions on Engineering Management***, 49(4): 365-374.

Liu, A., & Walker, A. 1998. Evaluation of Project outcomes. ***Construction Management and Economics***, 16: 209-219.

Loch, C. L., Stein, L., & Terwiesch, C. 1996. Measuring development performance in the electronics industry. ***Journal of Product Innovation Management***, 13: 3-20.

Lundgren, A. 1995. ***Technological Innovation and Network Evolution***. London: Routledge.

Luo, Y.-L. 2001. ***National Innovation System of Taiwan*** (1st ed.). Taipei: National Science Council.

Lynn, G., & Reilly, R. 2000. Measuring team performance. ***Research and Technology Management***, 43(2): 48-56.

MacCormack, A., Verganti, R., & Iansiti, M. 2001. Developing products on "Internet Time": the autonomy of a flexible development process. ***Management Science***, 47(1): 133-150.

Maddox, J. 1988. Theoreticians thrive among dunes. ***Nature***, 336(17): 199.

Mansfield, E. 1988. The speed and cost of international innovation in Japan and the United States: external vs. internal technology. ***Management Science***, 34(19): 1157-1168.

Mansfield, E. 1998. Academic research and industrial innovation: An update of empirical findings. ***Research Policy***, 26: 773-776.

Mansfield, E., & Lee, J. L. 1996. The modern university: contributor to industrial innovation and recipient of industrial R&D support. ***Research Policy***, 25: 1047-1058.

Manunta, G. 2000. ***Research: Concepts, Issues and Paradigms***. Swindon, UK:

Cranfield Security Centre.

Marshell, H. 2002. What do we do when we code data? ***Qualitative Research Journal***, 2(1): 56-70.

Martin, M. J. C. 1984. ***Managing Technological Innovation and Entrepreneurship***. Reston, Virginia: Reston Publishing Company Inc.

Mason, R. O. 1979. The role of management in science. ***Public Administration Review***, 39(2): 112-116.

May, T. 2001. ***Social research: issues, methods and processes*** (3rd ed.). Buckingham: Open University Press.

Maylor, H. 2001. Assessing the relationship between practice changes and process improvement in new product development. ***Omega The International Journal of Management Science***, 29: 85-96.

Maylor, H. 2003. ***Project Management*** (3rd ed.). Essex: Pearson Education Limited.

McMillan, G. S., Narin, F., & Deeds, D. L. 2000. An analysis of the critical role of public science in innovation: the case of biotechnology. ***Research Policy***, 29(1): 1-8.

Meyer-Krahmer, F., & Schmoch, U. 1998. Science-based technologies: university-industry interactions in four fields. ***Research Policy***, 27(835-851).

Meyer, A. D., Brooks, G. F., & Goes, J. B. 1990. Environmental Jolts and industry revolutions: organisational responses to discontinuous change. ***Strategic Management Journal***, 11: 93-110.

Meyer, A. D., Loch, C. H., & Pich, M. T. 2002. Managing project uncertainty: from variation to chaos. ***IEEE Engineering Management Review***, Third quarter: 91-98.

Meyer, M. H., Tertzakian, P., & Utterback, J. 1997. Metrics for managing research and development in the context of the product family. ***Management Science***, 43(1): 88-111.

Miles, D. B., & Huberman, M. A. 1994. ***Qualitative Data Analysis*** (2nd ed.). London: SAGE Publications Ltd.

Miller, D. B. 1986. ***Managing Professionals in Research and Development***. San Francisco, CA: Jossey-Bass Inc.

Miller, W. L., & Morris, L. 1998. ***Fourth Generation R&D***. New York: John Wiley & Sons, Inc.

Milliken, F. J. 1987. Three types of perceived uncertainty about the environment: state, effect, and response uncertainty. ***Academy of Management Review***, 12(1): 133-143.

Mintzberg, H., & McHugh, A. 1985. Strategy formation in an adhocracy. ***Administrative Science Quarterly***, 30(2): 160-197.

Moorman, C., & Miner, A. S. 1998. The convergence of planning and execution: improvisation in new product development. ***Journal of Marketing***, 62: 1-20.

Morgan, C. P., & Henrion, M. 1990. ***Uncertainty: A guide to dealing with uncertainty in quantitative risk and policy analysis***. Cambridge: Cambridge University Press.

Mowery, D. C., & Rosenberg, R. 1978. The influence of market demand upon innovation: a critical review of some recent empirical studies. ***Research Policy***, 8.

Myers, S., & Marquis, D. G. 1969. ***Successful Industrial Innovation***. Washington, DC: Natural Science Foundation.

Narin, F., Hamilton, K., & Olivastro, D. 1997. The increasing linkage between US technology and public science. ***Research Policy***, 26: 317-330.

Nobelius, D. 2004. Towards the sixth generation of R&D management. ***International Journal of Project Management***, 22(5): 369-375.

Nohria, N., & Gulati, R. 1996. Is slack good or bad for innovation? ***Academy of Management Journal***, 39(5): 1245-1264.

Nonaka, I. 1991. The knowledge-creating companies. ***Harvard Business Review***, 69-104(6): 96.

Normann, R. 1971. Organisational innovativeness: product variation and reorientation. ***Administrative Science Quarterly***, 16(203-215).

NSC. 2003. White paper on Science and Technology: visions and strategies for the development of science and technology (in Chinese). Taipei, Taiwan: National Science Council.

NSC. 2005. Yearbook of Sciences and Technology Taiwan 2004 (in Chinese). Taipei, Taiwan: National Science Council, TAIWAN.

O'Connor, G. C., & McDermott, C. M. 2004. The human side of radical innovation. ***Journal of Engineering and Technology Management***, 21: 11-30.

OECD. 1980. The Frascati Manual. Paris: OECD.

OECD. 2006. ***OECD Biotechnology Statistics - 2006***. Paris: OECD Publishing.

Ojanen, V., & Vuola, O. 2006. Coping with the multiple dimensions of R&D performance analysis. ***International Journal of Technology Management***, 34(3/4): 296-318.

Oliver, A. L. 2001. Strategic alliances and the learning life-cycle of biotechnology firms. ***Organization Studies***, 22(3): 467-489.

Oliver, A. L. 2004. Biotechnology entrepreneurial scientists and their collaborations. ***Research Policy***, 33: 583-597.

Omta, S. W. F. 1995. ***Critical Success Factors in Biomedical Research and Pharmaceutical Innovation***. Dordrecht: Kluwer.

Omta, S. W. F., & de Leeuw, A. C. J. 1997. Management control, uncertainty, and performance in biomedical research in universities, institutes and companies. ***Journal of Engineering and Technology Management***, 14: 223-257.

Ortt, J. R., & Smits, R. 2006. Innovation management: different approaches to cope with the same trends. ***International Journal of Technology Management***, 34(3/4): 296-318.

Pandit, N. R. 1996. The creation of theory: a recent application of the grounded theory methods. ***The Qualitative Report***, 2(4): http://www.nova.edu/ssss/QR/QR2-4/pandit.html.

Pangarkar, N. 2003. Determinants of alliance duration in uncertain environments: the case of the biotechnology sector. ***Long Range Planning***, 36: 269-284.

Pappas, R. A., & Remer, D. S. 1985. Measuring R&D productiviity. ***Research Technology Management***, May-June.

Partington, D. 2000. Building grounded theories of management action. ***British Journal of Management***, 11(2): 91-102.

Patterson, W. C. 1993. Evaluating R&D performance at Alcoa Laboratories. ***Research Management***, March - April: 23-27.

Patton, M. Q. 1980. ***Qualitative evaluation methods***. London: Sage Publications.

Pavitt, K. 1991. What makes basic research economically useful? ***Research Policy***, 20: 109-119.

Pavitt, K. 2001. Public policies to support basic research: what can the rest of the world learn from US theory and practice? (And what they should not learn). ***Industrial and Corporate Change***, 10(3): 761-779.

Pawar, K. S., & Driva, H. 1999. Performance measurement for product design and development in a manufacturing environment. ***International Journal of Production Economics***, 60-61: 61-68.

Pearson, A., Nixon, W. A., & Kerssens-van Drongelen, I. 2000. R&D as a business - what are the implications for performance measurement? ***R&D Management***, 30(4): 355-366.

Peças, P., & Henriques, E. 2006. Best practices of collaboration between university and industrial SMEs. ***Benchmarking: An International Journal***, 13(1/2): 54-67.

Peters, T. J., & Waterman, R. W. 1982. ***In search of Excellence***. New York: Harper and Row.

Pinto, J. K., & Mantel, S. J. 1990. The causes of project failure. ***IEEE Transactions on Engineering Management***, EM-37(4): 269-276.

Pisano, G. P. 1994. Knowledge, integration and the locus of learning - an empirical-analysis of process-development. ***Strategic Management Journal***, 15: 85-100.

Pisano, G. P. 1997. ***The Development Factory-Unlocking the Potential of Process Innovation***. Boston, MA: Harvard Business School Press.

Pisano, G. P. 2006. Can science be a business? Lessons from biotech. ***Harvard Business Review***, October: 114-125.

PMI. 2004. ***A Guide to the Project Management Body of Knowledge*** (3rd ed.). Upper Darby, PA: PMI.

Poh, K. L., Ang, B. W., & Bai, F. 2001. A comparative analysis of R&D project evaluation methods. ***R&D Management***, 31(1): 63-75.

Powell, T. C., White, D., Koupt, K. W., & Owen-Smith, J. 2005. Network dynamics and field evolution: the growth of interorganistional collaboration in the life sciences. ***American Journal of Sociology***, 110: 901-975.

Powell, W. W., Koput, K. W., & Smith-Doerr, L. 1996. Interorganizational collaboration and the locus of innovation: networks of learning in biotechnology. ***Administrative Science Quarterly***, 41: 116-145.

Powell, W. W., & Owen-Smith, J. 1997. Universities as creators and retailers of intellectual property: life sciences research and economic development. In B. Weisbrod (Ed.), ***To Profit or Not to Profit***. Cambridge, MA: Cambridge University Press.

Reiner, G. 1989. Winning the race for new product development. ***Management Review***, 78(8): 52-53.

Ritchie, B., & Marshell, D. 1993. ***Business Risk Management***. London: Chapman & Hall.

Robertson, A. 1974. Innovative management. ***Management Decision Monograph***, 12: 6-16.

Robson, C. 2002. ***Real World Research: A Resource for Social Scientists and Practitioner-Researchers*** (2nd ed.). Oxford: Blackwell Publishers.

Rogers, E. M. 1983. ***Diffusion of Innovation***. New York: Free Press.

Rogers, H., Ghauri, P., & Pawar, K. S. 2005. Measuring international NPD projects: an evaluation process. ***Journal of Business and Industrial Marketing***, 20(2): 79-87.

Roman, D. 1964. Project management recognizes R&D performance. ***Academy of Management Journal***, 7(1): 7-20.

Rothaermel, F. T., & Deeds, D. L. 2006. Alliance type, alliance experience and alliance management capability in high-technology venture. ***Journal of Business Venturing***, 21: 429-460.

Rothwell, R. 1992. Successful industrial innovation: critical factors for the 1990's. ***R&D Management***, 22(3): 221-239.

Rothwell, R. 1994. Towards the fifth-generation innovation process. ***International Marketing Review***, 11(1): 7-31.

Rothwell, R., & Zegveld, W. 1985. ***Reindustrialization and Technology***. Harlow: Longman.

Roussel, P. A., Saad, K. N., & Erickson, T. J. 1991. ***Third Generation R&D: Managing the Link to Corporate Strategy***. Boston, Massachusetts: Harvard Business School Press.

Salomo, S., Gemünden, H. G., & Leifer, R. 2007. Research on corporate radical innovation systems - a dynamic capabilities perspective: an introduction. ***Journal of Engineering and Technology Management***, 24(1): 1-10.

Sandstrom, J., & Toivanen, J. 2002. The problem of managing product development engineers: can the balanced scorecard be an answer? ***International Journal of Production Economics***, 78: 79-90.

Sapienza, A. M. 2005. From the inside: scientists' own experience of good (and bad) management. ***R&D Management***, 35(5): 473-482.

Saunders, M. N. K., Lewis, P., & Thornhill, A. 2000. ***Research Methods for Business Students*** (2nd ed.). London: Prentice Hall.

Schmid, E. F., & Smith, D. A. 2002. Should scientific innovation be managed? ***Drug Discovery Today***, 7(18): 941-945.

Shenhar, A. J., Tishler, A., Dvir, D., Lipovetsky, S., & Lechler, T. 2002. Refining the search for project success factors: a multivariate, typological approach. ***R&D Management***, 32(2): 111-126.

Shohet, S. 2004. Editorial: R&D biotechnology - the management challenges. ***Journal of Commercial Biotechnology***, 10(4): 301-303.

Sobek II, D. K., Liker, J. K., & Ward, A. 1998. Another look at how Toyota integrates product development. ***Harvard Business Review***, 76(4): 36-49.

Song, X. M., & Montoya-Weiss, M. M. 1998. Critical development activities for really new versus incremental products. ***Journal of Product Innovation Management***, 15: 124-135.

Spekman, R. E., Lynn, A. I., MacAvoy, T. C., & Forbes III, T. 1996. Creating strategic alliances which endure. ***Long Range Planning***, 29(3): 346-357.

Stainer, A., & Dixon, B. 2003. Productivity and performance measurement in R&D. ***International Journal of Technology Management***, 13(5/6): 486-496.

Stake, R. E. 2000. Case Studies. In N. K. Denzin, & Y. S. Lincoln (Eds.), ***Handbook of Qualitative Research***, 2nd ed.: 435-454. Thousand Oaks, CA: SAGE.

Strauss, A., & Corbin, J. 1990. ***Basics of Qualitative Research***. London: SAGE.

Sullivan, L. P. 1988. Policy management through quality function deployment. ***Quality Progress***, June: 18-20.

Sun, C.-L. 2004a. The challenges of university-industry collaboration in biotechnology industry in Taiwan (in Chinese). ***Taiwan Economic Research Monthly***, 27(2): 75-78.

Sun, C.-L. 2004b. The relationship between the performance based on the adaptation of types of innovation of Taiwan biotechnology firms (in Chinese). ***Taiwan Economic Research Monthly***, 27(2): 37-48.

Tapon, F., Thong, M., & Bartell, M. 2001. Drug discovery and development in four Canadian biotech companies. ***R&D Management***, 31: 77-90.

Tashakkori, A., & Teddlie, C. 1998. ***Mixed Methodology: Combining Qualitative and Quantitative Approaches***. London: Sage Publications.

Terziovski, M., & Morgan, J. P. 2006. Management practices and strategies to accelerate the innovation cycle in the biotechnology industry. ***Technovation***, 26: 545-552.

Tether, B. 2002. Who co-operates for innovation, and why: an empirical analysis. ***Research Policy***, 31: 947-967.

Tidd, J., Bessant, J., & Pavitt, K. 2005. ***Managing Innovation: Integrating Technological, Market and Organisational Change*** (3rd ed.). Chichester, UK: John Wiley & Sons Ltd.

Turner, B. 1981. Some practical aspects of qualitative data analysis: one way of organising the cognitive processes associated the generation of grounded theory. ***Quality and Quantity***, 15: 225-247.

Turner, J. R., & Cochrane, R. A. 1993. Goals-and-methods matrix: coping with projects with ill defined goals and/or methods of achieving them. ***International Journal of Project Management***, 11: 93-102.

Turpin, T., & Deville, A. 1995. Occupational roles and expectations of research scientists and research management in scientific research institutions. ***R&D Management***, 25(2): 141-157.

Turpin, T., Garrett-Jones, S., & Rankin, N. 1996. Bricoleurs and boundary riders: managing basic research and innovation knowledge networks. ***R&D Management***, 26(3): 267-282.

Tushman, M. L., & Anderson, P. 1986. Technological discontinuities and organisational environments. ***Administrative Science Quarterly***, 31: 439-465.

Tushman, M. L., & Moore, W. 1988. ***Readings in the Management of Innovation***. Cambridge: Balling Publication.

Twigg, D., & Voss, C. A. 1991. ***CAD/CAM in simultaneous engineering***.

Unit B.2, R. D. 2002a. Provisions for implementing integrated projects: 1-17. Brussels, Belgium: European Commission.

Unit B.2, R. D. 2002b. Provisions for implementing networks of excellence: 1-20.

Brussels, Belgium: European Commission.

Utterback, J. 1971. The process of technological innovation within the firms. ***Academy of Management Journal***, 14: 75-88.

Utterback, J., & Abernathy, W. J. 1975. A dynamic model of process and product innovation. ***Omega***, 3(639-656).

Valentine, N. 1991. ***BP Chemical Commercial System: IT Risk and Project Management***. Fontanebleau, France: INSEAD.

Van de Ven, A. H., & Rogers, E. M. 1988. Innovations and organisations - critical perspective. ***Communication Research***, 15: 632-651.

van der Panne, G., van Beers, C., & Kleinknecht, A. 2003. Success and failure of innovation: a literature review. ***International Journal of Innovation Management***, 7(3): 309-338.

Veryzer, R. 1998. Discontinuous innovation and the New Product Development process ***Journal of Product Innovation Management***, 16: 363-376.

Ward, A., & Liker, J. K. 1995. The second Toyota paradox: how delaying decisions can make better cars faster. ***Sloan Management Review***, 36(3): 43-61.

Ward, S., & Chapman, C. 2002. ***Project Uncertainty Management as a Desirable Future***. Southampton: University of Southampton.

Wass, V. J., & Wells, P. E. 1994. Research Methods in Action: An introduction. In V. J. Wass, & P. E. Wells (Eds.), ***Principles and Practice in Business and Management Research***: 1-34. Hampshire, England: Dartmouth Publishing Company.

Wateridge, J. 1995. IT projects: a basis for success ***International Journal of Project Management***, 13(3): 169-172.

Wheelwright, S., & Clark, K. 1992. ***Revolutionizing Product Development: Quantum Leaps in Speed, Efficiency and Quality***. New York: Free Press.

Whelan, J. M. 1976. Project profile reports measure R&D effectiveness. ***R&D Management***, 19(5): 14-16.

Williams, T. M. 2005. Assessing and moving on from the dominant project management discourse in the light of project overruns. ***IEEE Engineering Management***, 52(4): 497- 508.

Yin, R. K. 2003. ***Case Study Research: Design and Methods***. California: SAGE Publications.

Zaltman, G., Duncan, R., & Rogers, E. M. 1973. ***Innovations and Organisations***. New York: Wiely.

Zucker, L., & Darby, M. R. 1998. Intellectual human capital and the birth of US biotechnology enterprises. ***American Economic Review***, 1: 290-306.

Zucker, L., & Darby, M. R. 2000. Capturing technological opportunity via Japan's start scientists: evidence from Japanese firms' biotech patents and products. ***Journal of Technology Transfer***, 26: 37-58.

Zucker, L. G., & Darby, M. R. 1997. Present at the biotechnological revolution: transformation of technological identity for a large incumbent pharmaceutical firm. ***Research Policy***, 26: 429-446.

Appendix

Appendix A: Interview Template

BACKGROUND (REGARDING THE 'CONTEXT' AND 'ACTOR' CONSTRUCTS IN THE FRAMEWORK)

Asking about the background of the interviewees and the projects

Natures of the projects – e.g. the project purpose, the project structure, the field of the project, the level innovativeness of the project, the size in terms of funding of the project, the size of the project in terms of number of collaborators, the duration of the project, etc.

Background information about the university scientists and the industrial managers involved in the project – educational background, titles in academic and industrial sectors, research experience and reasons for conducting the projects, position occupied in the project

What experience of project management did you have at the time this project commenced?
In what sense were other projects you have conducted similar to this project?

USE OF PROJECT MANAGEMENT PRACTICES (REGARDING THE 'PROCESS' CONSTRUCT IN THE FRAMEWORK)

Asking about actions taken for managing the project

What did you do to manage the project?

Why did you deploy the processes/practices mentioned?

How did you use them?

What was required to enable they use?

Why did you not use these project management practices to manage the project? (showed the practices mentioned in project management literature to the interviewees)

Would you please describe the whole process regarding managing the project?
Was there any difficulty in managing the project?

Was there any difference to managing an academic project?

What was the difference?

What factors caused the differences?

PERFORMANCE OF THE PROJECT (REGARDING THE 'OUTCOME' CONSTRUCT IN THE FRAMEWORK

Asking about project success/failure and performance of the project

Was the project evaluated as a success/failure?

Why did you evaluate the project as a success/failure?

What does success/failure mean for you?

Did other stakeholders view these differently?

IMPACTS OF THE USE (REGARDING THE PATTERNS BETWEEN 'PROCESS' AND 'OUTCOME')

Asking about the relationship between use of project management practices and the project performance

Overall, what were the main reasons for the project success/failure?

Did the use of project management practices contribute to the project success/failure?

Please could you specifically indicate which project practices contribute to the project success/failure? To what extent?

Please could you state why the project management practices contribute to the project success/failure?

EVIDENCES OF USE

Is there any documentary material that can be collected or read to support the statements you made above?

Appendix B: Web Based Survey Questionnaire

UNIVERSITY OF BATH
SCHOOL OF MANAGEMENT

Questionnaire for the survey of the use of project management and project performance

Confidentiality: all information given will never be identified with you personally or your organisation, and will never be used by any third party.

This questionnaire aims at understanding the use of project management by university scientists, which may be associated with the performance of their projects.

Please spare some time to answer questions based on the project which has been completed and is vivid in your mind.

Appendix

No.	Questions / Statements	Not at all ← extent of agreement → Highest
A: actions related to the use of project management practices		
No.	Questions / Statements	Not at all ← extent of agreement → Highest
1	I set up the project objectives at the initial stage of the innovative project.	1------2------3-------4------5
2	I monitored the project progress by the identified project objective during the projects.	1------2------3-------4------5
3	I set up project milestones at the initial stage of innovative projects.	1------2------3-------4------5
4	I monitored the project progress by the identified project milestones during the projects.	1------2------3-------4------5
5	Please indicate to what extent you monitored project progress by regular meetings.	1------2------3-------4------5
6	I never changed the defined project objectives during the life cycle of the innovative projects.	1------2------3-------4------5
7	I never changed the defined project milestones during the life cycle of the innovative projects.	1------2------3-------4------5
8	Please indicate how many times the identified project objective was during the projects.	01 □ nil 02 □ 1 03 □ 2 04 □ 3 05 □ 4 06 □ 5 90 □ non-applicable
9	Please indicate how many times the identified project milestones were changed during the project.	01 □ nil 02 □ 1 – 2 03 □ 3 – 4 04 □ 5 – 6 05 □ 7 – 8 06 □ 9 – 10 07 □ 10 and above 90 □ non-applicable
B: performance of the research project		
No.	Questions / Statements	Not at all ← extent of agreement → Highest
10	Please indicate to what extent the innovative project, being executed by you, met the project objective within the proposed schedule according to the research proposal.	1------2------3-------4------5
11	Please indicate to what extent the innovative project, being executed by you, met the project objective within the proposed budgets according to the research proposal.	1------2------3-------4------5
12	Please indicate to what extent the innovative project, being executed by you, met the project objective according to the research proposal.	1------2------3------4------5
13	Please indicate to what extent the innovative project, being executed by you, continuously received follow-up research funding. (Based on the projects you conducted in 2002 - 2004)	1------2------3------4------5
13	What was the value of the project in New Taiwan Dollar (NTD)?	01 □ 400,000 and below 02 □ 400,001 – 700,000 03 □ 700,001 – 1,000,000 04 □ 1,000,001 – 1,300,000 05 □ 1,300,001 – 1,600,000 04 □ 1,600,001 – 1,900,000 04 □1,900,001 and above 90 □ non-applicable

Appendix

14	Please indicate what was the number of research team members for the projects.	01 □ 5 staff and below 02 □ 6 – 10 staff 03 □ 11 – 15 staff 04 □ 16 – 20 staff 05 □ 21 staff and above 90 □ non-applicable
C: background information		
No.	Questions / Statements	Low ← extent of agreement → High
15	Please indicate what kind of research organisation you are working for.	01 □ Universities or academic research institutes 02□ Semi-public R&D laboratories in public sector 03 □ R&D laboratories in private sector 90 □ non-applicable
16	Please indicate what your title is.	01 □ Professor or equivalent 02 □ Associate professor or equivalent 03 □ Assistant professor or equivalent 90 □ non-applicable
17	Please indicate how many years you have been running your own research laboratory.	01 □ three years and below 02 □ 3.1 – 5 years 03 □ 5.1 – 10 years 04 □ 10.1 – 15 years 05 □ 15.1 years and above 90 □ non-applicable
18	Please indicate what the nature of the research project was.	01 □ basic research 02 □ applied research 03 □ developmental research 90 □ non-applicable
19	Please indicate what category your research project belonged to.	01 □ biomedicine 02 □ agriculture biotechnology 03 □ bio-pharmaceutics 04 □ medical engineering 05 □ bio-informatics 06 □ food biotechnology 90 □ non-applicable
20	Was the project….?	01 □ academic research projects 02 □ commissioned project 90 □ non-applicable
21	Was the project….?.	01 □ individual research projects (please go to question 26) 02 □ collaborative research projects 90 □ non-applicable
22	How many collaborative research laboratories, including your laboratory, were involved in the project?	01 □ 2 02 □ 3-5 03 □ 6-10 04 □ 11and above 90 □ non-applicable
23	What was your position in the project?	01 □ Head of collaborative research project 02 □ Co-PI 03 □ PI 90 □ non-applicable
24	All of the collaborators approached the project goal from different aspects at the same time.	1-----2-----3-----4-----5
25	All of studies taken by the collaborators were sequentially arranged.	1----2-----3-----4-----5
D: productions		
No.	Questions / Statements	Low ← extent to agree → High
26	Please indicate how many SCI papers have published or been accepted during the period from 2002 to 2004?	01 □ 1 – 3 02 □ 4 – 6 03 □ 7 – 9 04 □ 10 – 12 05 □ 113 and above 90 □ non-applicable (please indicate the reason

		_______)
27	Please indicate how many patents have been granted and filed during the period from 2002 to 2004?	01 □ 0 02 □ 1 – 2 03 □ 3 – 4 04 □ 5 – 6 05 □ 7 and above 90 □ non-applicable
Please leave your contact details if you want to have a copy of the outcomes of this study. Thank you. Name： Department： Tel： Email：		
The questionnaire is finished. Thank you for your time filling it in.		